A new technology for strengthening soils as an intangible resource for investment-building projects

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Abstract. The effectiveness of intellectual activity in construction is determined by the relevance and the possibility of practical application of its results in the implementation of investment and construction projects. The investment attractiveness of the territory depends to a large extent, including on the construction site's ground conditions. Analysis of scientific research conducted by Russian and foreign researchers shows that the solution of this problem is possible due to the strengthening of soils. Areas of application of soil reinforcement technology are identified. The analysis of existing technologies carried out in the field of increasing the load-carrying capacity of soils has been carried out, and the main shortcomings of the methods have been identified. A new technology for strengthening soils with crushed stone piles is proposed. The main problems are researched, and the ways of their solution are considered in case of applying the proposed technology.

One of many problems of the current stage in the development of the Russian economy is the low effectiveness of introducing the results of scientific research into practice. It is well known [1, 2, 3] that many enterprises underestimate the possible possibility of obtaining a significant economic effect from using the intangible resources in practical activities. Let's consider a specific example.

In this paper, the main problems of the Irkutsk region are identified; they need immediate solution when developing built-up areas, as well as areas characterized by complex ground conditions.

The old and dilapidated housing stock worsens the appearance of cities, hinders the development of urban infrastructure, lowers the investment attractiveness of the territories. In addition, it is one of the sources of social tension, since the majority of citizens living in dilapidated and emergency homes are not in the position to independently acquire or receive housing of satisfactory quality. According to the Territorial Body of the Federal State Statistics Service for the Irkutsk Region, as of January 1, 2015, there were 58,456.2 thousand sq m, including 3161 thousand sq m of dilapidated housing and 1,029 thousand sq m of emergency housing. The number of citizens living in such houses amounted to 209

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thousand people. Significant destruction of dilapidated housing was due to deteriorations in soil characteristics, including due to design errors, construction, and operation in the past.

For new construction in the Irkutsk region, there are land areas that have obviously low engineering and geological indicators (bogs, loose, subsidence soils, and others).

Also the Irkutsk region, and, first of all, Irkutsk itself has a unique historical and cultural heritage, which has regional, all-Russian, and world significance. The preservation and restoration of monuments of history and culture is one of the most important tasks of our society. However, many objects are in an emergency condition.

The problem of the deteriorating geotechnical conditions of built-up areas is acute because of changes in hydrogeological conditions. Groundwater in the central part of Irkutsk is opened at the depth of 0.2 to 6.5 meters [7]. By definition, the territory is considered flooded if the groundwater surface lies at a depth of less than 3 meters. Already as of 1997, half of the center of the city got into the criterion area 47%. In the most acute form, flooding manifests itself in loose soils and a cultural layer. The rising groundwater level is due to hydraulic engineering construction, losses from pressure water-bearing systems, and buildings' self-flooding. Losses from storm sewage can be the main cause of the general rise in the level of groundwater.

Geotechnical engineers check certain geotechnical aspects of the stability of the designed and existing buildings. Usually, natural soils have sufficient strength without the need of any improvement in their load-bearing capacity. However, if the study of soils shows that they are not sufficiently strong, then several solutions of existing or developing problems are possible.

The main traditional methods of increasing the bearing capacity are: physical-chemical, mechanical, and constructive [6].

Taking into account the content of technological processes (materials, equipment, working operations) for strengthening the foundation soils, natural and climatic, engineering-geological and technogenic conditions of the Irkutsk region, it should be noted that practically all of them have significant technical, economic, environmental, and other shortcomings, excluding the possibility or expediency of their wide application in practice.

The main indicator of this conclusion is the real experience and the volume of reinforcement of the foundation soils in the conditions of the Irkutsk region, which are grouped into the following blocks (Table 1).

Table 1. Volumes of ground reinforcement in the conditions of the Irkutsk region.

Not Applicable	It is applied extremely limitedly	Applicable
silicification	pressure carburizing	ground cushion
resinization	hydrojet technology	superficial
thermal method	sheet piling	layer packing
claying	anti-filtration curtains	
bituminization		
reinforcement		
deep sealing		

The main factors affecting the restriction of applying a wide range of the above technologies should be considered: high costs; lack of guarantees of the construction objects' stability and quality; ecological and seasonal aspects; engineering geological conditions.

Thus, replacing the soil with the laying process and layer-by-layer compaction, as a rule, with a sandy-gravel mixture currently remain the main reinforcement of the base soils. The method is extremely laborious, requiring the utilization of significant amounts of

recoverable soil, transportation costs in the presence of waste, including ensuring the stability of the walls of deep excavations, especially in densely built-up areas or in the presence of a high level of groundwater.

All of the foregoing raises specific tasks for the search for alternative technological solutions in the field of foundation engineering, related to the optimization of work on strengthening the foundation soils in various engineering geological and technogenic conditions.

As a universal method for strengthening soils, including the conditions of the restricted construction of the Irkut-Invest LLC since 1999, the technology of deep compaction of soils with crushed stone (crushed stone-cement) piles has been developed and implemented at the facilities of the Irkutsk Region, which can be attributed to a variety of soil piles. It should be noted that along with the elimination of subsidence properties and the consolidation of loose soils in new construction, the chipped piles are widely used to improve the physico-mechanical characteristics of the foundation grounds of existing buildings and structures. The essence of the method is to fill the leader well with a diameter of up to 160 mm, passed without excavation, with gravel or dry crushed stone-cement mixture and with its layer-by-layer compaction by shock-vibration loading.

Fig. 1. Principal technological scheme for the formation of a chipped pile.

In some cases, instead of crushed stone, local soil, sand, or cement-sand mixture can be used.

As a result, a ground (gravel or concrete) pile with a diameter of 250-400 mm is formed in the soil massif. In this case, the radius of essential compacting of the soil is 0.3-0.9 m, depending on the type of soil and its initial physico-mechanical characteristics. The depth of the pile structure is not limited, at the same time, the most technically and economically justified is the compaction of the soil to a depth of 5.0-6.0 m.

The main equipment for this type of work is the small self-propelled drilling rigs UBW and BO of the German company "BAUER." The first one, UBW, uses the hydraulic hammer of the KRUPP company as the standard attachments. The second one, BO, relies on domestic hammers of mass production. When performing work in cramped conditions (inside buildings and structures), the pneumatic impact drilling machine (NKR type) is used being equipped with a hammer, or its analogs.

When passing through the well, a special tip of the impact projectile, close to the flat one, is used, which makes it possible to create significant horizontal stresses in the ground that promote the expansion of the well. Choosing the tip's shape and its diameter is determined by the power of the basic equipment, the condition and efficiency of soil compaction, and also by the rate of well penetration.

In the presence of interlayers of dense soil, in the case of insufficient equipment, the working shell has a limited rotational motion in combination with the vibrational load. After the well is built, its filling with ground material is done piece by piece in separate layers with a height of 0.4-0.6 m, depending on the material used, followed by compaction with a vibro-impact load to the required failure. The step between the ground piles, the failure rate when compaction of the soil supplied to the well and its flow rate are determined by the results of the trial works at this site.

It should be noted that the most stable results for compaction of foundation soils are achieved in soils with the same physicommechanical characteristics for the depth of the well.

When the chipped piles are installed, the soil layer is decomposed and decompressed to a depth of 0.5-1.0 m, counting from the surface, which should be taken into account in the process of technological design and preparation of the substrate. Reduction of the negative influence of soil piles on the soil surface layer can be achieved by reducing the intensity of compaction of the soil in the upper part of the well or the corresponding ground loading with a thickness of 1.0 m.

Positive results with the use of inclined crushed stone piles are achieved when the foundation soils are compacted under the foundations of existing buildings and structures. In this case, the excavation of the soil is excluded, and the ground of the foundation is included in the work directly during the process of piling.

As indicated above, the radius of the compaction zone around the pile depends, with all other conditions being equal, on the initial characteristics of the soil: the particle size distribution, humidity, density, specific adhesion, etc. As a result of drilling a well with the displacement of the soil to the sides (with the subsequent filling of their rubble), a dense zone forms around them. The maximum values of the dry soil's specific gravity is 17.8-17.2 kn/m^3 , which decrease with distance from the pile stem. The greatest zone of compaction is characteristic of silty-clay soils of low humidity. With increasing humidity to the state of full moisture capacity, the compaction zone is significantly reduced. In sandy soils, the maximum compaction zone is achieved at the optimum humidity (10-12%). With a decrease or increase in humidity relative to the optimum, the sealing effect decreases sharply [8].

In addition to improving the properties of the soil along the length of the pile, its seal is sufficiently high in the bottom of the well. In this case, a sealing zone is formed that is close to the shape of the ellipsoid of revolution or the ball and can be traced up to 1.0 m, depending on the type of foundation soil and its physico-mechanical characteristics.

Analyzing the experience in the construction of crushed stone piles, we identify a number of significant technological advantages:

1. Stable dynamic parameters of hinged vibro-impact equipment allow improving the building properties of soils, leveling them along the site and depth, which is most important for heterogeneous soils.

2. Local, low-power vibro-impact on the ground only in the well zone excludes its dynamic impact on adjacent buildings and structures, which is especially attractive for the reconstruction and restoration of old buildings and emergency facilities in part of the foundation soil.

3. The rigid fastening of the working crown on the drill rod ensures a strictly defined direction of pile formation and its predetermined position in the soil massif.

4. The presented technology is practically not limited by any ground conditions or technogenic factors, including when performing work under water.

5. Chipped piles are used both for new construction and for the production of repair and restoration works, as well as for reconstruction of buildings and structures, including objects of historical and cultural heritage, since the dynamic impact on the foundation soils and foundations is minimized.

Fig.2. Organization of the working area of the drilling rig when installing a slab foundation on subsidence ground.

Fig. 3. Operation of the UBW “BAUER” drilling rig in cramped conditions.

For a broader implementation of this technology, it is necessary to solve problems relating primarily to the regulatory and methodological support for the design and application of domestic equipment based on existing production experience and new research.

Strengthening of soils will make it possible to use land plots that obviously have low building performance, as well as to restore the correct operation of load-bearing elements of existing buildings, monuments of cultural heritage, and emergency housing objects with the appropriate feasibility study.

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