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Evaluation of Technical and Economic Efficiency of the Device Foundations of High-Rise Residential Buildings

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***Abstract* – The construction of multi-storey residential buildings is associated with many problems, since the underground part is exposed to a large number of risks during design and construction. The paper analyzed and proposed the most appropriate option for the device foundation for a multi-storey residential building. An expedient option is revealed by comparing different types of foundations by technical and economic indicators: labor intensity, duration of work, the wages of workers and estimated cost.**

Keywords – slab foundation; strip foundation; pile foundation.

I. INTRODUCTION

When designing buildings and structures, one of the most difficult issues is to solve problems in the construction of foundations. Designing the construction, the engineer himself decides the question of choosing building materials. When designing the foundations, the engineer must take into account the soil strata existing at the construction site and use their construction qualities to make the most rational decisions. Quite often, an engineer must design underground structures for an already selected type of structure. The task of the engineer designing the foundation in this case is limited, and the resulting solution is not always rational and economical. The design of foundations, in particular, the evaluation of soils as bases for buildings and structures (foundation, walls, framework, floors, etc.), should be dealt with when choosing a construction site, placing construction objects on it, their configuration, number of storeys and main supporting structures [1]. Additionally, during the design process, the method of excavation and foundation construction should be selected. With the wrong method of production of these works, soils can receive significant damage to their natural structure.

To obtain the most economical solution when designing foundations, the task should be considered comprehensively, while simultaneously evaluating the following issues [1-6]:

1) the choice of supporting structures of structures that work satisfactorily under these soil conditions;

2) possible deformations of the foundation soils;

3) the method of excavation and foundation work, ensuring the need to preserve the natural structure of soils.

This makes the task of designing foundations much more difficult than is commonly believed, as sometimes it is necessary to make adjustments to the supporting structures of the structure itself and to solve issues of production work.

Since reliable and medium quality soils are quite common, foundation design issues are set out mainly for medium conditions. The task of designing is reduced to the choice of a bearing layer of soil, the depth of the foundation and the construction of foundations, the determination of their dimensions, which guarantee reliable spatial rigidity and stability of buildings and structures.

Sometimes the underground floors during construction are arranged with the aim of lightening the weight of the building and leveling the uneven precipitation.

When designing foundations in difficult ground conditions, it is necessary to take into account the joint work of foundation soils and supporting structures, as well as to regulate the production of excavation works on foundation pits and foundation works from the standpoint of preserving the soil structure. As a result, when designing foundations, they determine the nature of measures aimed at preserving the structure of the foundation soil, without detailing and calculations, which are carried out in the design of the work.

The construction of multi-storey buildings is fraught with many problems. But if the safety of the stability of the above-ground part of buildings is related to the quality of materials and the human factor, then their underground part is exposed to a much greater number of risks. To calculate and anticipate them all is very difficult. Therefore, the design of foundations for high-rise buildings is perhaps the most difficult and crucial moment in the construction process. From the success of the initial phase of work depends on the durability of the building under construction and buildings located in the neighborhood.

When designing the foundation of a multi-storey building, take into account its height and design features. The building can be in the form of a single tower or a whole group of buildings of different heights, united by a common stylobate. Naturally, the higher the building, the more it puts pressure on the foundation. The total vertical load can reach impressive values. Not every soil can withstand such pressure. Engineering and geological surveys are one of the most important preparatory measures for the preparation of a project for the construction of multi-storey buildings. The building plot is subjected to ultrasound scanning, wells are drilled in the ground to a depth of 100 meters. At different levels, soil samples are taken to determine their composition. The general rule is that the denser and harder the ground, the better. The ideal option is the construction of the foundation of a multistory or high-rise building in rocky soil. Dense rock is well perceived vertical and horizontal loads from the elements of the foundation. In general, the construction of multi-storey buildings is possible on different soils, from plastic clay to rock. However, for each type of soil conditions it is necessary to choose your own type of foundation.

The magnitude of the vertical load on the foundation and the characteristics of the soil are two main factors influencing the choice of the type of foundation of a multistory building. However, other factors are subject to careful consideration [1-6]:

- the presence of seismic activity or stress of natural and man-made rocks in the construction area;
- presence of groundwater sources, underground rivers, quicksands, karst voids and other subsurface anomalies;
- location of large capital construction projects in the neighborhood;
- passing in the immediate vicinity of transport communications, subway tunnels, gas and water pipelines and other objects that can either affect the integrity of the foundation, or suffer as a result of the inevitable soil shrinkage;
- climatic factors - primarily seasonal temperature changes, the frequency of thunderstorms and wind speed. Its strong impulses, as well as thermal expansion of materials, as well as lightning strikes can cause very tangible one-time loads on the entire structure of the building, including the foundation.

II. Methods and Materials

Since each specific construction project, as well as the contracting organization that implements it, has its own characteristics and technical capabilities, there are always many constructive and organizational and technological solutions with the expected technical and economic indicators of the implementation of possible design solutions [7]. The purpose of the study is to substantiate the approach to reducing the complexity, cost, and duration of the foundation of a residential building based on the choice of the most economically viable option. A reasonable option is achieved by comparing the types of foundations for technical and economic indicators. The goal identified a number of more specific research objectives:

- to analyze the domestic and foreign experience of the device foundations of multi-storey buildings;
- perform the calculation of the base and foundations for a specific multi-storey residential building;
- to simulate the projected indicators of cost, labor intensity, duration of work on the representative object (residential building).

A huge role in the development of the science of engineering geology, soil mechanics, foundations and foundations have been played by domestic scientists. As the weight of the erected structures increased, builders began to pay more attention to the issues of foundation engineering and the assessment of soil deformation at the base. The first major theoretical work on soil mechanics should be considered Coulomb's theory (1773) on the pressure of soils on retaining walls. In the modern formulation, the theory of limit equilibrium of soils is developed by Soviet researchers V.V. Sokolovskii, V.G. Berezantsev, M.V. Malyshev and others.

A great contribution to the development of engineering geology made V.D. Lomtadze, V.V. Okhotin, V.A. Priklonsky, F.P. Savarensky, E.M. Sergeev, M.I. Sumgin and others.

The development of the issues of soil deformations assessment and the calculation of foundation sediments, started abroad by K. Terzagi, has received significant development in our country due to the large volumes of construction in the works of N.M. Gersevanov, N.A. Tsytovich, V.A. Florin, N.N. Maslov, M.N. Goldstein, K.E. Egorov, B.I. Dalmatov and many other domestic scientists. Studies of soil creep are highlighted in the works of S.S. Vialov, S.R. Meschan, Yu.K. Zaretskii, A.Ya. Budia and many others.

A lot of work has been done to evaluate the properties and deformability of structurally unstable soils. The work of N.A. Tsytovich, S.S. Vialov and others; loess soils - works by Yu.M. Abelev, N.Ya. Denisov, A.K. Larionov and others; peaty soil - the work of L.S. Amorian, N.N. Morarescula and others.

Soil deformability under dynamic effects was studied by D.D. Barkan, P.L. Ivanov, N.N. Maslov and others.

In the calculation of the foundation beams and plates on elastic foundation merit attention the works by M.I. Gorbunov-Posadov, I.A. Simboliai, B.N. Semochkin, A.P. Sinitsyna, etc.

Numerous studies are devoted to the evaluation of joint work of load-bearing structures of structures with deformable base. In particular, B.D. Vasilyev, S.N. Klepikov, D.E. Polshin, A.B. Fadeev and others were engaged in these issues.

These and many other works performed by Soviet scientists, served as the basis for the creation of the theory of calculation and design standards of bases and foundations.

Over the past 30 years, foundations on natural foundations have in many cases been replaced by pile foundations. A great contribution to the development of settlements and the use of pile foundations was made by A.A. Bartolomei, B.V. Bakholdin, N.M. Gersevanov, V.N. Golubkov, B.I. Dalmatov, F.K. Lapshin, A.V. Pataleev, Y.V. Rossikhii, Y.G. Trofimenkov, etc. In recent times increasingly piles made in soil (printed) are used. This was facilitated by studies conducted by E. L. Khlebnikov, A.A. Luga, F.K. Lapshin, E.M. Perley, etc.

III. MAIN SECTION WITH RESULTS AND THEIR ANALYSIS

The choice of a particular type of foundation, materials, method of its construction depends on many interrelated factors. The most important thing in making decisions is to take into account that the building and the natural foundation on which it stands, interact in a certain way with each other, and the foundation is an intermediate link in a single, very important chain. These elements have a physical, and even chemical, influence on each other; certain forces begin to act between them. Therefore, they need to be considered only in unity.

The foundation determines the strength and reliability of the entire structure. Efficiency, laboriousness and pace of construction of a building largely depend on its correct and rational performance.

The building, with its weight through the foundation, presses on the foundation, compresses it, as a result of which powerful stresses arise. The issues of determining the bearing capacity of the soil (including in the horizontal direction) and its resistance to deformation become topical. A weak base can not withstand the loads and cause precipitation, subsidence, lift, horizontal shear, roll, deflection, bending, twisting, oscillations of the foundation - all this can cause serious deformations.

The most important aspect of the foundation/primer interaction is the frictional force and cohesion between them.

In case of unsatisfactory condition of the soil, which cannot serve as a reliable basis, it is fixed (compaction, silicification, cementation, bituminization). Binding grounds is a complex technological task, which can only be implemented by organizations specializing in this. This type of work requires the creation of a separate ground fixing project.

To select the type of foundation, the soils are divided into heaving and non-cracking. Loose bases easily pass and retain water. In winter, they are saturated with moisture, freeze through and increase in volume by about 15%. The soil expands, rises (and unevenly) and pushes the foundation to the top. During thawing the ground along with the building settles. Such seasonal movements cause serious loads on the foundation. Looseness of soils directly depends on their density, dispersion, groundwater level. Soils of this type include silty and fine sands, clay soils, coarse-grained, filled with clay. The most unfavorable in this regard are clay bases. The problem of frost heaving is solved by the use of columnar or low-buried foundations with increased rigidity of the aerial part, although there is a misconception “the deeper the foundation is laid - the more reliable”.

Depending on what kind of load the buildings have on the ground, they are conventionally divided into light and heavy ones. If the heaving force exceeds the weight of the building, it is a light construction, and it is usually built on a shallow foundation. Whereas a building whose weight exceeds the total tangential heaving forces is considered heavy. To redistribute this mass a large deep foundation is being built.

The weight of the structure and, accordingly, the choice of foundation is mainly influenced by the wall material. Obviously, the light will be wooden buildings - frame, log, made of timber. Quite other foundations are necessary for heavy brick, block, concrete, multi-storey buildings with bearing slab floors - usually they are made of reinforced concrete, tape or pile type.

The choice of the type of foundation (configuration) is influenced by the constructive type of the building, which determines the spatial location of the main bearing elements - walls, floors, supporting columns. In some cases, the nature of the operation of the building may be taken into account, for example, will it be heated or cold. It is very important whether the building will have buried rooms that will need to be carefully protected from groundwater.

The foundation connects the above-ground part of the bottom, is a kind of belt for load-bearing walls, restraining internal stresses. It takes the full load of the building, redistributes its mass. This structural element is the lowest, it is under the greatest pressure, it is affected by the entire building, which upon completion will have a certain integrity. The foundation must absorb loads that often act non-uniformly, which causes not only squeezing, but also tensile and shearing forces that act from above.

The foundation carries the weight of the building to the ground. The building through the foundation is held in the ground, and retains its design position. The foundation can be affected by various forces: lateral shifting, tilting, sliding, pushing, etc. The foundation does not always rely on a fairly solid stable base, which is why it is so difficult to build on loose and mobile soils.

Based on the above, it is possible to draw some intermediate conclusions. The foundation must be:

- strong enough to withstand and effectively redistribute the load;
- resistant to shifting, pushing, tipping forces;

- durable, that is, to have a service life of not less than the building itself;
- neutral to the effects of groundwater;
- economically sound and least time consuming during construction.

In the practice of foundation engineering, a number of constructive solutions have been developed for foundations for frame multi-storey buildings with increased height: pile foundations, used in the form of driven piles of square or rectangular cross-section, printed piles of various systems, shells foundations on a natural basis: tape - in the form of parallel (not intersecting) or cross-strips; slab - in the form of ribbed or flat girders.

The choice of the type of foundation depends on the size and type of loads, the nature, bearing capacity and deformability of the base soils.

Foundation design is carried out for all stages of its construction - transportation and storage of elements, direct installation and operation. Development is carried out on the basis of the customer's specifications. However, in order to correctly select and calculate the foundation, it is necessary to have a sufficient amount of information [6].

First, the detailed characteristics of the future building will be required. We need, in fact, a detailed project containing:

- information on the size, configuration and materials of construction;
- data on space-planning decisions;
- information on the loads transferred to the foundation.

Particular attention is drawn to the presence and nature of underground spaces: basements, garages, ground floor.

Secondly, it provides a site plan with reference to the terrain, elevations, indicating the relative position of all possible structures. It is desirable that a network of tracks and platforms, a scheme for laying in-depth communications, be developed and marked in advance. It is also necessary to develop a landscape design and nature of landscaping, since these moments significantly affect the water balance of the territory.

Thirdly, it is necessary to carry out engineering-geological and hydrological exploration at the site (this work can be trusted only to licensed organizations). These surveys will determine the bearing capacity, the resistance of the base, and its other features. There will be data on the relief and positioning of the site; seismic conditions; type and physico-mechanical properties of soils, their reservoir location; the presence and level of groundwater, their balance and mode of oscillation, the chemical composition of water (aggressiveness with respect to building structures); monitoring of adverse geological processes - part-time processing, landslides, karst, temperature anomalies; freezing depth.

Geological and hydrological exploration is recommended not only in the built-up area, but also near the site.

Fourthly, the class of responsibility of this structure is indicated, which determines the requirements for maximum deformations. For this study, this will be the “normal” level of responsibility (second class), which is accepted for mass residential construction.

Fifth, in case of insufficient information or special difficulty of conditions, field measurements and monitoring are applied.

The developer makes a number of very important decisions and displays them in the relevant drawings and explanations. He should [1, 3-5]:

- depending on the type of building, determine the actual load on the soil and stresses arising in the base of the foundation;
- calculate the stability of the building;
- justify the use of a specific type of foundation;
- determine the possibility of using a natural base, or justify the organization of an artificial base;
- elaborate the design of the foundation, possibly several options (zero mark, axes, sections of knots and pits, specifications, reinforcement schemes, formwork characteristics, drawings of finished reinforced-concrete roducts);
- select a material (concrete grade, reinforcement section, etc.);
- calculate the depth of the foundation of all elements;
- select/propose the most cost-effective and less labor-intensive way to build a foundation.

In addition to the drawings, the project includes a list of regulatory documents for which the project was developed, as well as an explanatory note on the source data (surveys) and analytical studies of the decisions made by the developer. The basis for the calculations of the foundation is a number of regulatory sources [8-11], as well as more than two dozen related manuals are used.

Next, we will consider information about the representative object – this is a building that is being designed in the western part of Belgorod. The territory of the projected building is located on the border of two physical and geodetic zones - mixed forests and forest-steppe. Geomorphologically, the construction site is characterized by absolute marks of 185-183 meters. The upper part consists of clay soils, which are interbedded. In some areas during drilling, bright clays of the Neogene system are found, which are blurred in places to an absolute elevation of 154 m.

Underground waters during drilling are fixed within the limits of absolute elevations of 177-179 meters and belong to fluviaglacial deposits.

Seasonal fluctuations in the groundwater level are about 1.0 m relative to that recorded in the studies. The depth of seasonal soil freezing is 1.2 m.

The designed building is erected from monolithic reinforced concrete (concrete mixture density ρ = 2600 kg/m³). The building has a maximum height of 40.33 meters and includes 10 floors. Built-up area - 800 m². The building volume of the building is 31360 m^3.

The building looks like a three-beam composition and has the shape of petals, which are placed relative to each other at an angle of 120 degrees (Fig. 1). Each petal of the building has a width of 18 meters and a length of 11.5 meters.

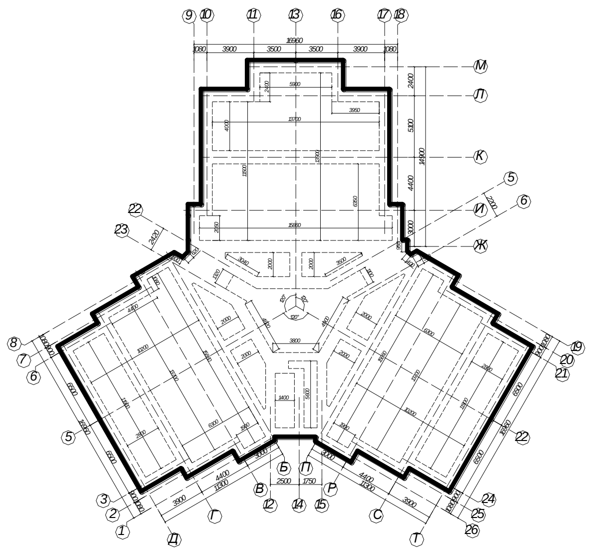

Fig. 1. Base Plate Plan

Based on a comprehensive computer analysis of engineering and geological data, it was decided to use three types of foundations:

- Foundation on a natural basis;
- Slab foundation;
- Pile foundations of deep laying.

In connection with the features noted above, when designing multi-storey buildings and high-rise buildings, the basic principles were developed, the basis of which was laid by architect Vitruvius in the 1st century AD in his treatise "Ten books on architecture" and further was developed by N.V. Nikitin - engineer, scientist, researcher, designer of Stalin's skyscrapers:

- strive to create an underground volume so that the weight of the extracted soil when building the underground part of the building is equal to the weight of the building;
- reduce pressure on the base of the foundation by increasing its area by creating a box-like foundation and developing the underground and stylobate parts of a building;
- to transfer the load on the foundations symmetrically relative to the central axis, using the appropriate structural scheme of the building;
- stiffness elements (monolithic walls, staircases, lift shafts, etc.) should be located symmetrically with respect to the central axis;
- the depth of the base of the building foundation should increase with increasing height of the building;
- apply (if possible) the pyramidal shape of the building;
- when increasing the height of the building, reduce the maximum permissible value of the draft of the foundation.

The choice of foundation design, in addition to the principles listed above, depends on the physico-mechanical characteristics and the nature of the bedding of the base soils and loads transferred to them, the shape and size of the high-rise building, the size of the construction site, the presence of surrounding buildings, tunnels (underground) and underground utilities, etc.

After analyzing all possible options for the device foundations in relation to the representative object, it was decided to design: slab foundation; strip foundation (monolithic grillage) on driven piles; strip foundation (monolithic grillage) on vibratory piles; strip foundation (monolithic grillage) on bored piles; massive tape monolithic foundation.

Indicators of the expected cost and complexity of work on the device of various types of foundations in relation to the object representative were determined using the software for budget estimates “GrandSmeta”.

Initially, a calculation was made on the main processes of the device foundations and a timetable for the execution of works. The schedule was built taking into account the combination of processes (flow method), to reduce the duration of work. The number of workers for the calculation of the duration of the work was taken according to the Unified Norms and Prices of the relevant processes.

According to the technological calculations, the accepted labor intensity for different versions of the foundations (Fig. 2) were summed up. The graph presented in Figure 2 shows that the device of the monolithic reinforced concrete slab foundation is the least time consuming, and the device of the monolithic reinforced concrete foundation is the most laborious.

The duration of the construction of the foundations for a multi-storey residential building is shown in Figure 3.

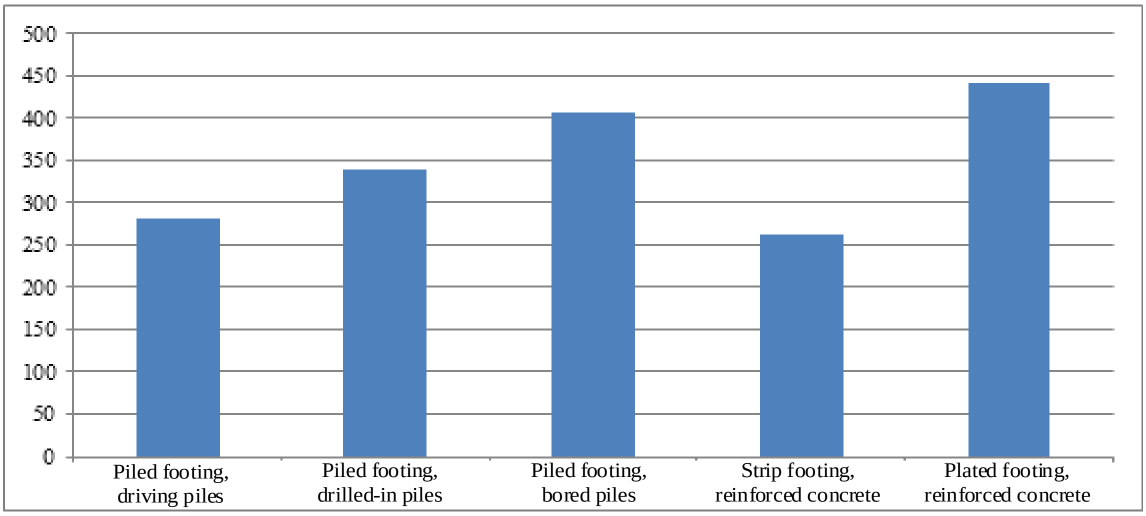

Fig. 2. The complexity of the device of various variants of the foundations for a multi-storey residential building, man-day.

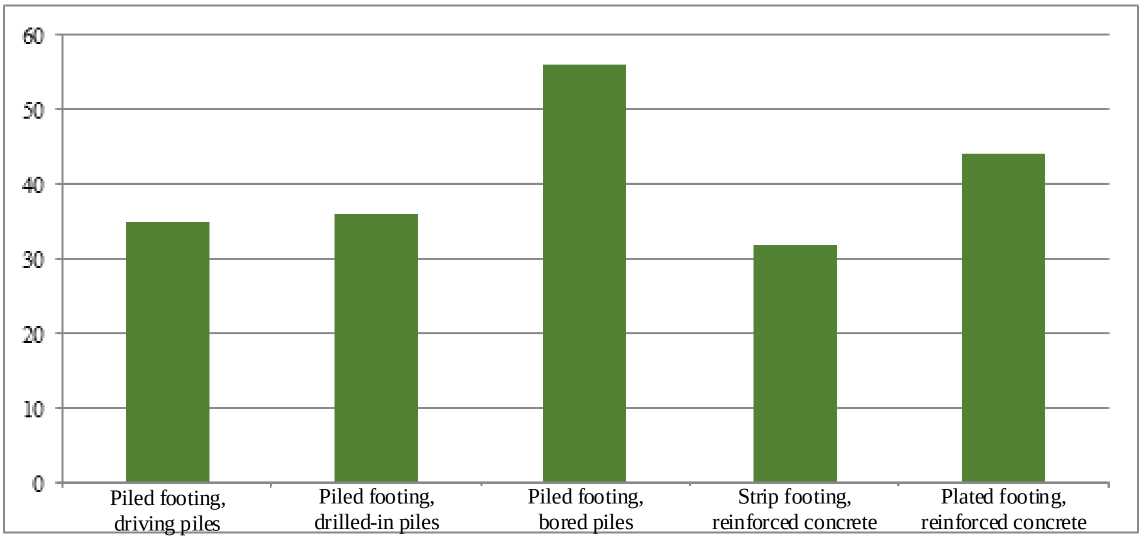

Fig. 3. The duration of the device various options for foundations for multi-storey residential building, days

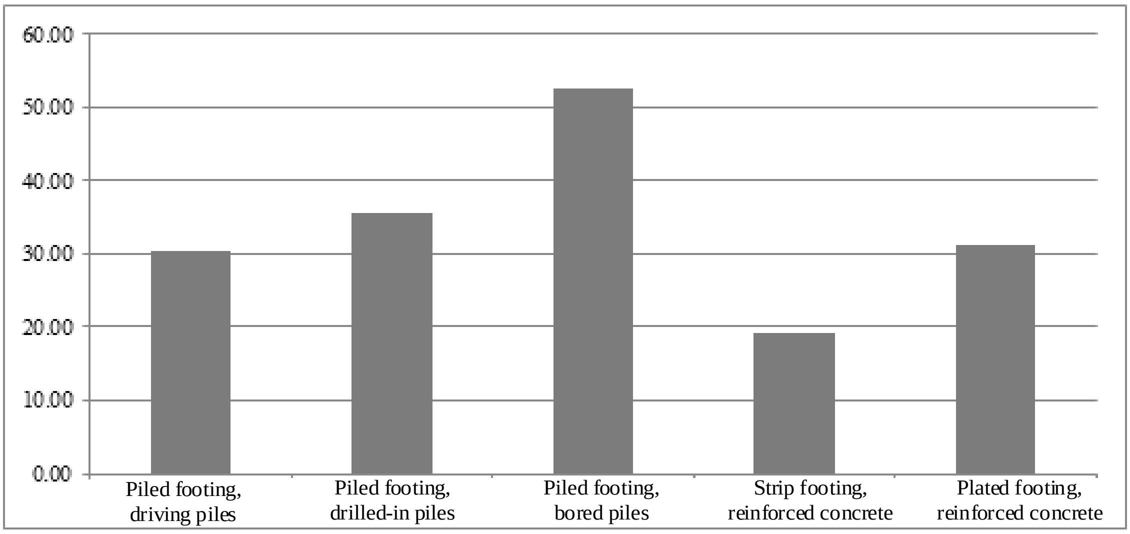

Fig. 4. Salaries of workers at the device of various variants of the foundations for a multi-storey residential building, thousand rubles.

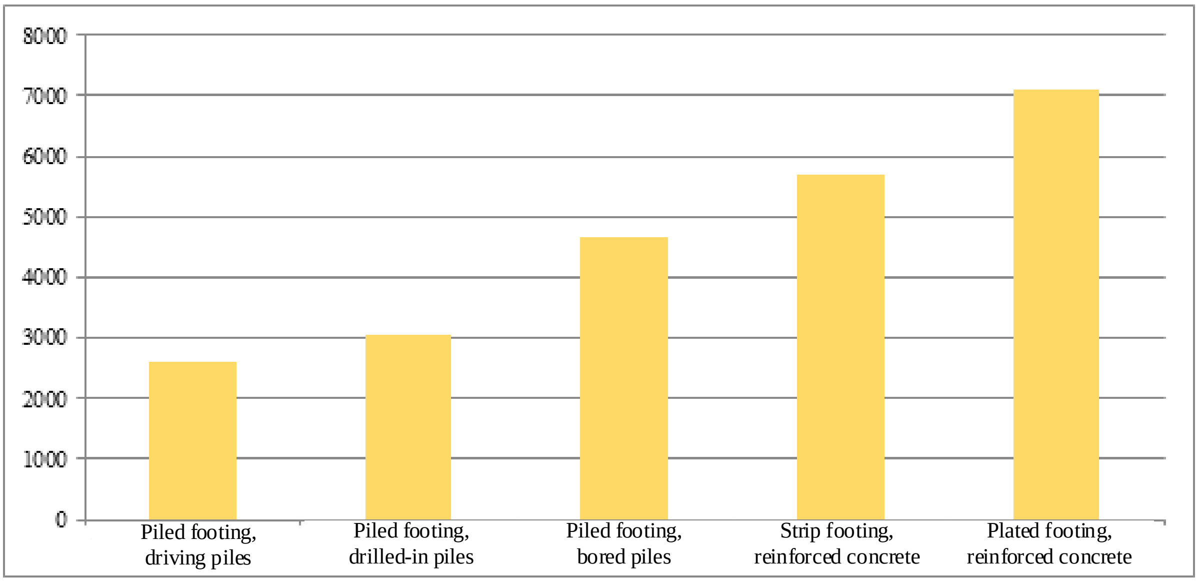

Fig. 5. Estimated cost of the device of various options for foundations for a multi-storey residential building, thousand rubles.

The data were obtained by plotting the processes for constructing various basement variants, observing the flow method. According to the schedule, the monolithic reinforced concrete slab foundation is the longest in terms of arrangement, and the longest pile foundation on bored piles is the longest.

The salaries of workers (Fig. 4) with the arrangement of various types of foundations are minimal when constructing monolithic reinforced concrete slab foundations, and maximum when arranging strip pile foundations on bored piles.

The estimated cost of building various types of foundations for a particular multi-storey residential building (Fig. 5) is as follows: the lowest cost has a strip foundation on driven piles, and the greatest value has a monolithic reinforced concrete foundation.

Analyzing the structure of the estimated cost of various options for the construction of foundations for a multi-storey residential building (Table 1), we can conclude that the use of materials and machine capacity in the installation of pile foundations is around 40% for three types of foundations (monolithic tape pile foundations (pile piles) , monolithic strip pile foundation (vibro-submerged piles), monolithic tape pile foundation (brown-stuffed piles). However, the material consumption is significantly different from the pile foundations of the ribbon and the foundation slab, which is within 90%.

Of all the technical and economic indicators, according to the authors, the most significant are the estimated cost and material consumption. Analyzing the research, we can conclude that the lowest estimated cost has a pile foundation for driving and vibrating piles. Also, this variant of the foundation is the least material-intensive.

TABLE I. STRUCTURE OF CAPABILITY OF A DEVICE OF VARIOUS TYPES OF FOUNDATIONS

Indicators	**The estimated cost of the device various foundations,%**				
	Monolithic strip pile foundation (driven piles)	***Monolithic strip pile foundation (vibro-submerged piles)***	***Monolithic strip pile foundation (bored piles)***	***Monolithic reinforced concrete slab foundation***	***Monolithic reinforced concrete strip foundation***
Materials	39.5	39.5	43.96	91.99	89.85
Machines and mechanisms	40.4	40.39	36.49	2.67	3.21
Payroll fund	6.61	6.63	6.38	1.94	2.55
Overhead	8.35	8.41	8.15	2.09	2.71
Estimated profit	5.15	5.18	5.02	1.31	1.68

IV. CONCLUSION

1. In this paper, the results of the study on the resource costs of the device of various types of foundations are reviewed and presented The work contains a comparison and identification of the most profitable variant of the device foundation of the building of a multi-storey residential building, located in the city of Belgorod on technical and economic indicators. A viable option is achieved by comparing the types of foundations and is as follows: domestic and foreign experience in building foundations for high-rise buildings has been analyzed; calculation of the base and foundations for a specific multi-storey residential building; simulated the projected cost and labor intensity of work on the representative object (residential building).

2. Analyzing the structure of the estimated cost of various options for the construction of foundations for a multi-storey residential building, we can conclude that the consumption of materials and machine capacity in the installation of pile foundations is in the region of 40% for three types of monolithic strip foundations. However, the material consumption of slab

and strip foundations is significantly different from pile foundations and is within 90%. In terms of material consumption, the basement variant with driving and vibrating piles has the smallest percentage (39.5%). A little more material consumption has a pile foundation on bored piles (43.96%). The ribbon and slab foundations have a significantly greater consumption of materials - 89.85 and 91.99%, respectively.

The estimated cost of the tape pile foundation on driven piles is 2,609,502 rubles, the pile foundation on vibrating piles is 3,044,273 rubles, the pile foundation on bored piles 4,654,196 rubles, slab reinforced concrete foundation 5,501,022 rubles monolithic reinforced concrete strip foundation - 7,083,441 rubles. The least costly in terms of material consumption and estimated cost are the pile foundation for driving and vibrating piles. In comparison with other types of foundations, the pile foundation on driven piles will be at 434,771 rubles cheaper than a pile foundation on piles; on 2 044 694 rub cheaper than pile foundations on bored piles, by 3,091,520 rubles cheaper than slab foundation and 4,473,939 rubles cheaper than a strip foundation.

3. The most expedient option for building a foundation for a multi-storey residential building according to the analyzed technical and economic indicators is a monolithic strip foundation on driven piles.

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