Geotechnical solutions for high-rise construction in the areas with significant elevation

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Abstract. The high attractiveness of the Black Sea coast in the Russian Federation, the ongoing work to create a world-class resort infrastructure lead to the need for the high-rise buildings’ construction and other heavy structures on steep grades that characterize most of the coastal strip. In such cases, they try to find the solutions that do not lead to a significant amount of earthwork when deepening the required number of floors under the stain of a high-rise building. However, with a large steepness of the relief, the excavation volume is always significant. Excavation during the engineering preparation of the territory and the development of deep pits leads to a loss of the slopes’ stability and, consequently, to the complex foundations’ solutions, engineering protection and overhead structures.

Introduction
Improving the design methods of high-rise buildings’ foundations in the areas with irregular soil compressibility and high seismicity is due to the use of modern geotechnologies and the introduction of original technical solutions by adapting the shape of the designed object to the existing terrain, which makes it possible to implement the planned architectural project in practice [1].

When choosing the main technical solutions for the high-rise buildings’ structures and foundations, in most cases it is necessary to deal with the initial geometric, physical heterogeneity and non-linearity of soils and materials. Different forms of high-rise buildings determine the methods of building foundations, and also require the preliminary detailed calculation and experimental justification of the methods used. A significant difference in elevation marks within the construction site of a high-rise building often leads to an irregular in plan and height shape of the projected object. In turn, such variable landforms are caused by the geomorphological features of the territory on which the high-rise construction is supposed. The combination of hazardous natural processes within a single construction site, such as seismicity, landslide impacts, variable groundwater level, the presence of weak soil layers in the upper part of the section, require significant engineering preparation of the territory [2] and in most cases lead to high cost of foundations and engineering protection, or the forced reduction of the base loads, i.e. to reduce the height, number of storeys, depth, which in turn changes and distorts the intended architectural appearance of an object. The practice of high-rise construction of the last decade in the Krasnodar Territory has shown that effective foundation designs help to significantly reduce the cost of performing the zero cycle and make it possible to save the intended architectural shape of the object and its parameters.

To search for the effective geotechnical solutions, it is important to study the nature of dangerous natural processes within the construction area and the peculiarities of the variable relief forms.
1. Complex and dangerous processes in the Krasnodar Territory

In the work carried out to date, which is based on a schematic map of the latest tectonics (Turbin L.I., Alexandrova N.V., 1979), as well as on the materials systematized when compiling a map of engineering-geological zoning of the Krasnodar Territory on a scale of 1: 200 000 (O. G. Vodopyanova, A.N. Baturina and others, 2005), a detailed classification of the Krasnodar Territory according to the development complexity for prospective construction was carried out [3]. In total, more than 630 types of soils have been identified in the Krasnodar Territory, systematized by the stratigraphic-genetic complexes within the engineering-geological areas, taking into account the geomorphological position.

Twelve engineering and geological regions are allocated in the Krasnodar Territory:
- Platform slopes of moderate deflections and uplifts;
- Armaviro-Nevinnomyssky Arbor;
- Adygea ledge;
- Foothill zones;
- Anticlinal zones of the Kerch-Taman periclinal deflection;
- Synclinal zones of the Kerch-Taman periclinal deflection;
- North Caucasian regional massif;
- Abino-Gunai zone;
- Block-fold zone of the Mountain Range;
- Goitkh-Achishkhinsky zone;
- Novorossiysk-Lazarevskaya zone;
- Gagro-Dzhava fold-block zone.

On the final map of the engineering-geological zoning, the areas favorable for construction (up to 20% of the territory), conditionally favorable for construction (up to 50% of the territory), unfavorable for construction (up to 30% of the territory) are highlighted. In general, according to the information collected and its systematization according to geotechnical conditions, an assessment is made of the territory suitability for construction from the standpoint of economic feasibility.

According to the results of the data long-term system analysis, it was established that there are practically no simple engineering and geological conditions within the Krasnodar Territory, they can be called simple conditionally. The need for engineering preparation on the territory of the varying complexity degrees is dictated by the objective geological factors [3].

Many investment-attractive sites are classified as unfavorable for construction, which determines a negative forecast for urban development investments in the development of such sites by the private investors. As a result, the territory zoning according to its suitability for construction led to the need to develop the methods for designing and building foundations in the described difficult ground conditions (see Figure 1) in conjunction with the peculiarities of the development of specific territories by the proposed types of buildings and structures, as well as taking into account the existing dangerous natural processes.

Also, a classification of foundation engineering methods is being developed, allowing to take into account the specific structural features of the Krasnodar Territory and the processes taking place in this territory, as well as the technical parameters of the facility or a group of facilities being built (quarter, micro-district, etc.).

2. Methods’ development for the foundations’ design and construction in difficult ground conditions in the Krasnodar Territory

The foundation design methods’ improvement is based on the results of the laboratory, field, numerical studies, as well as the obtained geotechnical monitoring data [5, 6]. In general, the structure of the methods is presented below.
The article discusses an example of adapting the foundation of the designed high-rise building to the existing processes and the natural topography shape of the construction site located on a landslide slope. It is highlighted in the structure of the developed methods (see Figure 1) and is one of the proven effective options for reducing the material consumption for the geotechnical solutions [7–15].

This example may be interesting to consider as the experience of geotechnical construction for other regions where the same large number of simultaneously acting complicating factors have been established.

Figure 1. Methods’ development for designing the buildings and structures’ foundations in difficult ground conditions in the Krasnodar Territory
3. The option to adapt the construction of the high-rise building’s foundation to the shape of the relief

The considered residential complex is located in Sochi in the immediate vicinity of the sea. The construction site has a bias of 20-25 degrees in two directions. The architectural project was developed by “Archiproject” Architectural Workshop LLC, SAP Zadikyan O.M.

The building has three blocks: one high-rise and two stylobate blocks. The high-rise block has a different number of elevated floors: in the southern part of the building there are 23 floors, in the northern - 18 floors, due to the configuration of the construction site relief.

Within the construction site, there is a significant difference in elevations (about 20 meters), active landslide processes are recorded, a 9-point design seismicity is established, therefore, a significant impact on the slope in the form of deep undercutting when setting the elevations for the construction of the foundation slab jeopardized the safe operation of all surrounding buildings due to the potential decrease in slope stability even when performing the massive engineering protection structures.

![Figure 2. The layout of a high-rise building on a landslide hazardous slope with the horizontal contours of the construction site’s natural relief](image)

When developing a more efficient and safe foundation option, it was decided to repeat the soil massif with the configuration of the foundation slab in the bearing layers’ surface, which led to the base plates’ differently buried soles introduction uniting the pile groups within the development spot (Figure 3, 4).
Figure 3. Scheme of the proposed multi-submerged foundation plates of the high-rise and stylobate parts in the complex with the absolute marks of the ledges’ bottom

Figure 4. Section 1-1 (see Figure 2) along the high-rise part of the building, combined with the engineering and geological conditions

At the same time, landslide and sloping processes were taken into account, for which the necessary construction of the foundation pit engineering protection was calculated, the foundation construction sequence was set based on the condition of minimizing the impact on the slope, taking into account the phased cut of the soil. After numerous calculations for the drilling marks’ selection, the final construction of the foundation on the slope is as follows (Figure 5).
Figure 5. A fragment of the design scheme for representing the plan-high-altitude location of the individual blocks’ foundation slabs and their spatial configuration (engineering and geological elements are not conventionally shown)

The working draft provided for the stages of the high-rise building piles construction at different elevations with the phased production of a foundation slab uniting them. The final one-piece concessive design of the plate was taken into account when performing the joint spatial calculations, including taking into account seismic effects and pulsating wind loads.

Figure 6. The construction phase of the high-rise and stylobate blocks’ foundations construction
Figure 7. The final stage of the high-rise building’s construction on a variable terrain

As a result of the calculations and the phased construction of a high-rise building with multi-buried foundations, their effectiveness was confirmed and a significantly less impact on the slope was achieved due to the fundamental construction repeating the nature of the bearing layers’ fall, and the experience of observing the object during the operation makes it possible to recommend this approach when developing the sites with complex terrain in similar geotechnical conditions [16,17].

Summary
The use of modern geotechnologies in combination with the foundation construction sequence specified by the project, as well as the adaptation of the space-planning solution of the projected object to the existing terrain, provides a technical and economic opportunity to put the planned architectural project into practice. This requires the appropriate calculation justification and the use of original and effective technical foundations’ solutions.

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