The role of underground urbanization in Samara city geological processes

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Annotation. In all largest cities due to lack of territory there is an intensification of underground space use - underground urbanization. It allows finding solutions to transport and environmental problems while preserving the unique appearance of the city's historical cents. However, the process of underground space development leads to activation of some exogenous processes, which may lead to negative consequences. More than one million people live in Samara city, subway line is built, there are subway objects of industrial and defense importance (bunkers) reaching considerable depth. Active underground construction leads to strengthening of geological processes (weathering, karst formation, suffosia, etc.), change of strength properties of rocks, violation of natural hydrological regime of the territory. By the example of Samara, stages of underground urbanization of the city were studied and its influence on geological processes was considered. Results of studying existing use of city underground space are described. Taking into account geological and geomorphological regionalization of the city, the areas, which underground space development is the most undesirable, were identified.

1. Introduction

At present, large cities are not only characterized by active development and growth of the city in width, but also the development of underground space - underground urbanization. According to international standards, the share of underground structures should be 20-25% of the total construction area. In the Russian Federation, this indicator is much smaller, but in the largest cities is gradually increasing, which allows the release of additional urban territory. Garages, warehouses, industrial and commercial enterprises, utility networks, administrative and cultural institutions, transport networks are being tried to be located underground. In some cities it is planned to create master plan of underground space development and create engineering-geological 3D-maps of districts and city blocks. Depth of the underground structures construction may reach 50 m. It is necessary to take into account existing environmental, especially geoeconomic features of the territory, including the possibility of activation of exogenous geological processes.

For the territory of Samara city, the problem of underground urbanization and its impact on engineering and geological conditions of construction has not been comprehensively studied before. In this article, for the first time, the city territory was zoned and the soil conditions of each district were analyzed. This study may be useful for planning further urban development, as it allows for taking into account information about the complexity of soil conditions.
2. Methods

Nowadays a lot of attention is paid to the issues of studying possibilities of using city underground space and consequences of underground urbanization [1-3].

The construction of underground structures on the territory of Samara began in the XVIII century, during the construction of the second Samara Fortress, where wood structures were erected to strengthen the slopes. This object is located on the territory of modern Bread Square in Samara and was studied during archaeological excavations in 2014, 2017 and 2019 (figure 1). It is shown that wooden structures were created to reduce landslide and erosion processes typical for the studied area at that time. At the same time, in order to level the surface around the fortress, powerful bulk layers (up to 7-8 meters high) were created, mainly from manure and construction debris [4-6].

**Figure 1.** General view of the archaeological excavation of Bread Square 2017 (A) and 2019 (B).

The next significant stage of development of the city's underground space was connected with the beginning of laying of municipal networks - Samara water pipeline in the end of XIX century. The plan of Samara city of 1885 (figure 2) already shows water pipe network (project of engineer N.P. Zimin), and in 1886 Samara water pipeline was opened. By early 1917, the total length of Samara water pipeline was about 70 km. At present, according to the official website of Samara Vodokanal ME, the city's water supply networks are more than 1500 km long, and the sewerage networks are more than 1200 km long.

Significant volumes of underground construction were carried out during the Great Patriotic War, when in Samara (then Kuibyshev) a system of defense facilities (bunkers) was built [7, 8]. In 1941, the city of Kuibyshev received the status of "Western Capital" which led to the large-scale construction of defense facilities underground (Down Underground Command Points - DOC). They include: one of the most famous shelters in Russia - "Stalin's Bunker", as well as "Bunker Kalinin" or Red Army ZKP (on Kuibyshev), "Bunker Zhukova" (on the 7th section), "Bunker Beria" or "Bunker NKVD" (near Bread Square), "Bunker Communications of the Soviet Navy". At present, the bunkers are in different states, for example, the Red Army ZKP is operational (command post of the Samara administration in case of emergency), Stalin's bunker is also operational and falls under the jurisdiction of the Ministry of Emergency Situations, but access to the bunkers is allowed, and most of the bunkers are abandoned, flooded by groundwater and destroyed.

In the middle of XX century in the conditions of confrontation and "Cold War" development of the city of Samara was carried out taking into account the need to create civil defense shelters. They can be divided into two types: blast shelters (equipped in the basement of houses) and bomb shelters factories. In Samara hundreds of blast shelters were created, most of which are now abandoned. During the Great Patriotic War, many businesses were evacuated to Kuibyshev. Bomb shelters built during and after the war were designed to survive in conditions of radioactive or biological contamination, they included shelters of plants "Progress", "Start", "ZiM" "GPZ № 4" and others. At present, most of them have been destroyed.
In 1980 in Kuibyshev the construction of the subway was started, and in 1987 the regular transportation of passengers began. At present the length of Samara Metro line is 11.6 km (total length of distillation tunnels and main tracks - 22.7 km), it consists of 10 stations (9 of them are underground and 1 aboveground). The deepest station of Samara Metro is "Gagarinskaya" (17.5 m), the deepest stations are "Sportivnaya", "Sovetskaya", "Pobeda" and "Bezymyanka" (about 8 m). At present, it is planned to continue construction of Samara Metro stations (figure 3).

![Figure 2. Plan of Samara city with indication of full network of water pipes according to engineer N.P. Zimin's project.](image)

The aim of the article is to study the features of underground urbanization on the territory of Samara and its impact on engineering and geological processes of the studied territory. In order to achieve the
set goal, the following tasks were solved: first, to study main stages of underground construction development on the city territory; second, to conduct engineering-geological zoning and give characteristics of main exogenous geological processes; third, to reveal the most dangerous territories where exogenous geological hazards may activate during underground construction development.

The methods of scientific literature source analysis, field survey and description, tabular and graphical methods were used in writing the article.

3 Results and discussions
Samara is located on the watershed and valleys of Samara and Volga rivers. Back in 1969 researches of doctor of geological and mineralogical sciences V.I. Rachitsky [9] have given the chance to divide territory of Samara (Kuibyshev) on engineering-geological conditions of building into seven areas with instructions of their features (figure 3).

![Figure 3. Plan of Samara city by indicating conditional borders of areas with different engineering and geological conditions of construction.](image)

*The first engineering and geological district* covers the floodplain of the river. Samara. Due to covering of this region with water in floods and permanent covering of lower areas with water after construction of Saratov HPP, this region is not suitable for construction including underground one.

*The second engineering-geological district* is confined to the valley of Samara River, representing the 1st ancient (Khvalynskaya) terrace above the floodplain. It covers a part of Kirovsky District on the right bank, Zubchaninovka, Smyshlyaevka settlements and an airfield. On the left bank - Kryazh village, new buildings area Volgar, oil refinery and several other plants. This area is represented by alluvial deposits in the form of laminated and oblique loams, sands and loams, with a maximum capacity of 25 m. The depth of the mirror of groundwater, representing a single aquifer with waters of floodplain sediments within the absolute markings of 30-40 m. In general, within the limits of the second area the rocks are characterized by the allowable load from 1.5 to 2.5 kg/cm² and are to some extent subsidence. Evaluation of the subsidence in each individual construction site should be made additionally. For development of underground construction the second engineering-geological district may be suitable, but at present it is not relevant for this territory of the city.
The third engineering and geological district is dedicated to the high part of Samara city from Polevoy St. to Khlebnaya Square. It covers the territory of distribution of Quaternary alluvial deposits of the 2nd ancient terrace at the confluence of the Volga and Samara rivers. Terrace logs are lowered by denudation processes and, especially on the Samara slope, are poorly expressed in relief. According to V.I. Rachitsky, this area is composed of layered and oblique ancient Quaternary alluvial sands and loams up to 30 meters thick. The thickness of the sand is covered with limestone and less often dolomites, and are partially suitable for construction. However, on the whole, this particular engineering and geological region is less favorable, as there are fears of meeting the karsted rocks of the Kazan Stage. The level of underground water, confined to the Kazan aquifer, is at absolute levels of 30 to 40 meters. In this area there are already underground construction objects ("Bunker Beria", underground wooden structures of the second Samara fortress of the XVIII century), in addition, the construction of new metro stations is planned in the near future. The third engineering and geological district is characterized by old buildings, a large number of cultural heritage objects, the preservation of which is necessary to maintain the unique appearance of the historic city center. Underground construction in this area will help to solve the problem of territory deficit, but requires a comprehensive analysis of all potential consequences of underground construction. For example, the problem of possible activation of karst processes requires additional engineering-geological studies.

The fourth engineering-geological district covers separate sections devoted to the Volga and Samara rivers watershed and its slopes. From the surface it is composed of a solid cover of raw and deluvial loams with the capacity of 5 to 25 meters. Underlying rocks on a large area are limestones, dolomites with lenses of gypsum and anhydrite of the Kazan upper Perm, on a smaller area - red-colored clays of the Tatar layer. There is no permanent aquifer in loams. In general, this engineering and geological region is suitable for construction, especially where raw and sometimes deluvial loams are covered with clays. This district is also favorable for underground construction development, currently it is here that Samara metro stations are located.

The territory where the lines and metro stations are located covers separate sections dedicated to the watershed of the Volga and Samara rivers, where the engineering and geological situation is generally favorable for construction. Ground waters in this area are much lower than the depth of mine workings. From the surface of the watershed is formed by a continuous cover of loams with capacity from 5 to 25 meters. Underlying rocks on a large area are limestones and dolomites, which may be subjected to karst formation, which requires detailed exploration.

In the course of engineering-geological processes and phenomena during the metro construction in uncemented sedimentary rocks, shifts and subsidence may occur. Above underground excavations on the surface of the ground may form subsidence muds with depth from 20 to 250 mm. Buildings and structures that are located in subsidence muds can be deformed. On this basis, the lines of the Samara metro are laid mainly under the highways.

The fifth engineering and geological district is located in the area of outcrops and close to the Akchagylsky Neogene clay layer to the north of Smyshlyaevka settlement. The clays are mostly very plastic and are capable of landslide on slopes, especially under additional load, which should be taken into account when building in this area. In general, this district is suitable for underground construction by its characteristics but it is not relevant at present.

The sixth engineering-geological district covers the area of distribution of brick-red clays of the Tatarskaya Formation of Sokka, in some places covered with loams of insignificant capacity. This district is confined to watershed squares in the northeastern part of the city (Clinical Hospital district) up to Mekhzavod. The clays consist of rare but rather powerful limestone layers and dense siltstone. These interlayers in some areas are close to the surface and can be a very reliable basis for heavy structures. On the whole, the district is quite favorable for construction. This district is also suitable for underground construction development; it is not relevant here yet.

The seventh engineering-geological district occupies a significant area, stretching a wide strip along the left–bank slope of the Volga River valley from Postnikov ravine to the northern boundary of the city, bounded by the Sok River. Limestones and dolomites of the Upper Carboniferous, Lower and Upper
Perm come to the surface or lie close to it within the area. The rocks are heavily encrusted. When designing a construction in this area, it is always necessary to thoroughly explore the thickness by drilling to the depth of the influence of the projected construction pressure. If karst cavities are identified, they should be cemented or other measures should be taken to prevent their harmful impact on the construction. In this area development of underground construction is urgent because of territory deficit, but it requires additional technical and constructive solutions.

The seven engineering-geological areas mentioned above and noted in figure 3 have their own geological features. They are being developed, but construction in these areas is often conducted in difficult geotechnical conditions.

An example of influence of active underground construction on geological processes in district 7 is rise of ground water level due to leaks from communications that causes strengthening of karst processes resulting in formation of underground and surface cavities. As a result, gaps and funnels are formed on the surface. Similar result can be seen in districts 3, 4 as a result of intensification of suffosi and seepage processes. On the territory of Samara city there are known cases of cavities formation under buildings that lead to formation of cracks and even collapse of walls. At one of the metro stations (district 4), the surface is lowered due to the load on roads located above the metro line.

Thus, underground construction is now one of the most perspective directions of town-planning activity. However, it may lead to significant changes in the speed of exogenous geological processes, as well as in the hydrological regime of surface and ground waters [10].

4. Conclusions
As a result of the conducted research, the following conclusions can be drawn:

1. In city of Samara there is a high demand for increase in volumes of underground construction for the solution of transport problems and rational use of city territory, thus for a city difficult engineering-geological and hydrogeological conditions of construction of underground constructions are characteristic.
2. Engineering and geological features of Samara city territory are characterized by high spatial heterogeneity of Quaternary and indigenous (prequaternary) rocks.
3. When developing the underground space it is necessary not only to raise requirements to safety of work performance during construction of the facility and its reliability during operation, but also to take into account its geoeological conditions, including the possibility of activating exogenous geological processes.

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