ENVIRONMENTAL SUSTAINABILITY IN THE DEVELOPMENT OF URBAN UNDERGROUND SPACE

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ABSTRACT. The application of reliability theory and risk in the field of underground construction permits on the basis of statistical processing of results of laboratory and industrial research to establish the laws of probability distribution of the studied parameters of the rock mass around an underground object. The obtained regularities, in turn, enable the prediction of durability of underground structures in order to introduce rational approaches in their design. This involves the following tasks: identification of ways to ensure ecological and technological reliability of underground objects depending on the applied technology of their construction and possible risks; modelling of construction technology in order to assess the safety and risk of development of underground space; development of ideas about the enforcement mechanism and criteria for eco-technological reliability of urban underground structures; optimisation of structural parameters of underground structures based on the concept of acceptable risk and technological and environmental safety; comprehensive assessment of the reliability of underground structures by using different technologies and methods for their construction.

Keywords: geoecological model, rockmass, underground construction

УСТОЙЧИВОСТ НА ОКОЛНАТА СРЕДА ПРИ РАЗВИТИЕТО НА ГРАДСКИ ПОДЗЕМНИ ПРОСТРАНСТВА

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РЕЗЮМЕ. Прилагането на теорията за надеждността и риска в областта на подземното строителство позволява на базата на статистическа обработка на резултатите от лабораторни и промишлени изследвания да се установят законите на вероятностното разпределение на изследваните параметри на скалната маса около подземен обект. Получените закономерности от своя страна дават възможност за прогнозиране на издръжливостта на подземните конструкции с цел въвеждане на рационални подходи при тяхното проектиране. Това включва следните задачи: идентифициране на начини за осигуряване на екологична и технологична надеждност на подземни обекти в зависимост от приложената технология на изграждане и възможни рискове; моделиране на строителните технологии с цел оценка на безопасността и риска от развитие на подземно пространство; разработване на идеи за механизма за прилагане и критерии за екотехнологична надеждност на градските подземни структури; оптимизиране на структурните параметри на подземните конструкции въз основа на концепцията за приемлив риск и технологична и екологична безопасност; цялостна оценка на надеждността на подземните конструкции чрез използване на различни технологии и методи за тяхното изграждане.

Ключови думи: геоекологичен модел, скална маса, подземно строителство

Introduction

Sustainable development of society is impossible without ensuring environmental sustainability, which is understood as the ability of the ecosystem to preserve its structure and functional characteristics under the influence of external and internal factors. At present, urban underground construction is becoming much more active in the world. Urban underground structures are the only real means to solve radically planning, transport and communal problems of urban areas. However, large-scale development of underground space of megacities requires substantial financial resources, a significant share of which is spent on combating infiltration of groundwater into underground structures and sanitation. The fight against water flows into the construction and operation of underground facilities in dense urban areas is associated with considerable difficulties and requires the use of special measures.

Materials and design of the lining do not always provide the necessary reliability of underground structures, and, consequently, their normal operation during a given service life period. Thus, up to 5% of the operated sewer tunnels in Moscow require annual overhaul due to failures of the lining caused by the aggressive impact of external and internal environment and other operating conditions [1]. About 40-45 thousand rubles per 1 m of the tunnel are spent on major repairs of such structures. Up to 30% of the initial cost of construction in the operation of communication tunnels is spent on the elimination of failures that occur much earlier than the estimated period. The consequences of failures are failures of the earth's surface, pollution of groundwater by industrial and domestic sewage, subsidence of buildings and underground structures themselves [3].

It should be taken into account that over the past 5 years, the number of industrial and domestic water discharges has increased significantly (in Moscow, up to 9 million m^3 of wastewater is discharged into sewer tunnels per day). In addition to quantitative changes in wastewater, there was also a qualitative change (the presence of a large percentage of the content of aggressive impurities). The latter is most often manifested in the enhancement of the aggressive properties of the medium [3]. As a result of the development of high-rise construction in large cities, inevitably there are significant loads on the lining of operated underground structures located in the construction zone.

According to [4], up to 70% of the garages, 60% of the warehouses, up to 50% of the archives and various storage facilities, up to 30% of the cultural institutions, up to 3% of the buildings of research institutes and universities can be located in Moscow below the level of the earth's surface [2], [3]. The city has more than 200 built underground passages and transport tunnels, among which the operated part of municipal tunnels exceeds 160 km. The annual input of such tunnels exceeds 15 km.

It is obvious that environmental sustainability in the development of the underground space of cities, which means the preservation of high operational reliability of underground facilities throughout their service life, is a very urgent task. Therefore, it is necessary to develop a geoecological model of underground construction on the basis of criteria of technological reliability and acceptable risk.

Problem definition

Reliability indicators include quantitative characteristics, which are introduced according to the rules of the statistical theory of reliability. Methods of the statistical theory of reliability at underground construction allow establishing requirements to reliability of components and elements of the underground construction on the basis of requirements to reliability of the natural and technical geosystem “rock massif – technology – underground construction – environment” as a whole.

The statistical theory of reliability is an integral part of a more general approach to the calculation of the reliability of technical objects, in which failures are considered as a result of the interaction of the object as a physical system with other objects and the environment. Thus, in the design of underground structures and their structures, it is necessary to take into account, in explicit or implicit form, the statistical spread of mechanical properties of materials, elements, as well as variability in time and space parameters characterising the external loads and effects on the system “rock mass – technology – design of underground structures – environment”. [5].

Most reliability measures are fully meaningful even with a more general approach to the estimated reliability. In the simplest model of calculating the design of an underground structure for strength according to the scheme “load parameter – strength parameter”, the probability of failure-free operation coincides with the probability that within a given period of time the value of the load parameter will never exceed the value that takes the strength parameter. Both parameters can be random functions of time.

The development of the underground space of cities is associated with complex physico-chemical and physico-mechanical transformations based on non-deterministic values and phenomena, so the technology of construction of the underground structure can be represented as a stochastic system, as evidenced by the following provisions [6]:

- underground construction is associated with a variety of random variables of prescription, technological, operational nature, factors of interaction of rock mass and the environment and external loads;
- such random factors in their relationship affect the reliability of the structures of the underground facility;
- rock mass around the underground structure is an anisotropic discrete medium, with components representing random variables. Variability of mining and hydrogeological conditions, soil properties, impact on the design of underground structures from the environment are random;
- soil softening in time – the result of interaction with the external environment. Failures occurring during the operation of structures of underground facilities are random events.

Thus, to determine the reliability of underground facilities, it is not enough to know the physical and chemical processes taking place at the same time and to rely on these practices. It is necessary to proceed from the general theory of reliability, applying its laws to calculate the degree of reliability and analytical prediction of changes in the reliability of structures.

For underground facilities of the city, which can be considered as a potential source of danger, an important concept is safety. Although safety is not a general concept of reliability, it is closely related to this concept under certain conditions (for example, when a violation of the working condition of the structures of an underground structure can lead to conditions harmful to people and the environment).

The concept of “risk” is directly related to the concept of safety, as if the reverse side of the latter. The existing methods of substantiation of technological parameters of structures of underground buildings based on deterministic models do not take into account the random nature of the filtering soil massifs and compositions used. Such a deterministic approach does not allow assessing the reliability of calculations of residual water inflows and the risks associated with the creation of the system “rock mass – technology – underground structure – environment”. Consequently, there is no possibility to optimise properly the technological parameters of underground construction. However, taking into account the risks and their factors is a very urgent task, especially in the context of optimising the technological parameters of the underground structures.

Modern approaches to safety and risk problems

Danger in underground construction is considered as a condition inherent in the natural and technical geo-system “rock mass – technology – lining – environment”. It is implemented in the form of damaging effects on humans and the environment in the event of its occurrence either in the form of direct or indirect damage in the normal operation of underground facilities.

The simplest optimisation formulation of the problem in the theory of safety and risk can be considered as a probabilistic modification of the usual least cost criterion. This model allows generalisations that take into account the costs associated with the diagnosis, prevention of failures of underground structures, repeated failures, repair and restoration, planned capital costs, etc.

The following factors are the disadvantage of optimisation approaches to safety and risk tasks:

- insufficient development of economic models,

- conditional character of numerical values of cost indicators,
- fundamental difficulties in assessing accidents in underground construction related to environmental and social damage.

To avoid such difficulties, optimisation approaches that do not use economic categories can be used. For example, if the safety of an underground facility can be ensured by purely technical measures that do not lead to high costs, the criterion of optimal safety is exempt from cost restrictions. As a result, we come to the principle of the minimum probability of an accident in underground construction.

In many cases, in urban underground construction, the cheapest solution corresponds to the highest risk and vice versa, the solution with limited risk requires high costs. This inverse relationship of risk and cost can determine the order of technical decision-making when justifying the method of strengthening the rock mass around the underground object.

When designing a particular underground facility with certain technical characteristics, the designer must take into account the issues of reliability. Specific tasks for reliability and evaluation of their implementation at all stages of the creation and operation of underground facilities allow to identify the weakest points and solve a number of tasks for optimal design, reservation, selection of quality of spare parts, establish the frequency and degree of preventive measures. To do this, all the information on the operation of the underground facility must be used.

Any requirement for reliability should be justified not only technologically, but also from an economic point of view. The choice of parameters of underground structures and structures that ensure efficiency, and safety of their operation, determines the need to obtain quantitative estimates of reliability or risk.

Research task

The application of the theory of reliability and risk in the field of underground construction on the basis of statistical processing of the results of laboratory and industrial research allows to establish the probability distribution laws of the studied parameters of the rock mass around the underground object. The resulting patterns, in turn, make it possible to predict the durability of underground structures and to achieve rational approaches to their design.

In this regard, the following tasks arise:

- identification of ways to ensure environmental and technological reliability of underground facilities, depending on the technologies used for their construction, and possible risks;
- modelling the construction of geotechnology objects for safety and risk assessment of underground space development;
- development of ideas about the mechanism and criteria of ecological and technological reliability of urban underground structures;
- optimisation of design parameters of underground structures based on the concept of acceptable risks and technological and environmental safety;
- comprehensive assessment of the level of reliability of underground structures in the application of various technologies and methods of their construction.

Comprehensive analysis of geological conditions of construction

The choice and justification of the technology of construction of underground structures should be carried out only on the basis of a comprehensive system analysis of mining conditions of construction according to the main determining factors, including:

1. Technical and technological solutions of underground facilities for the period of operation. This group of factors include:
   - functional purpose of the underground structure;
   - internal dimensions of the underground structure;
   - operational load indicators;
   - initial requirements for technical and technological reliability.
2. Engineering-geological and hydrogeological conditions of construction and operation of underground facilities. In this group, the determining criteria for the choice of construction technology include:
   - initial requirements for technical and technological reliability;
   - geological structure and engineering-geological characteristics of soils containing the object;
   - the depth of the structures;
   - influence of hydrogeological conditions on the construction and operation of the underground facility.
3. Social and ecological conditions of underground construction placement in the formed urban environment. This group of factors mainly considers the possible harmful effects of the environment and the construction (operated) underground facilities. The most significant features include:
   - nature of the earth's surface;
   - the presence of underground communications and structures;
   - provision of existing transport and pedestrian routes;
   - reducing the impact of negative construction processes on the urban environment.
4. The climatic conditions of the construction.
5. Economic conditions of construction. The defining indicators of this group are:
   - amount of capital investments;
   - preliminary cost of 1 m of the route of the passed underground construction;
   - terms of construction, etc.
6. The state of the technical base of the construction organisation.

Environmentally friendly construction technologies

The main objective of a scientifically based approach to the development of underground space, taking into account all environmental requirements, is the use of high technologies in underground construction.

High technology implies:

- the expansion of mechanised shield driving;
- broader use of the shield method of tunnelling underground structures in combination with advanced methods of strengthening of the array of the host rocks;
- greater use of Novoushitskogo method of tunnelling;

- expansion of the use of railway entries into the underground space to protect the environment of cities;
- application of various methods to prevent possible precipitation of the earth's surface during underground construction;
- creative use of the underground space of cities for the development of underground infrastructure, taking into account environmental requirements.

The up-to-date situation during the underground space development in the world is characterised by a number of features. In particular, the world practice of tunnel construction is focused currently on the placement of public infrastructure at an increasing depth. The need for deeper placement of underground structures is associated with the following main aspects:

- the near-surface levels are already quite saturated with various structures of urban infrastructure;
- the service life of many collectors has expired or is about to expire, making them hazardous in case of overloading with ever-increasing volumes of wastewater;
- the possibility of increasing the capacity of reservoirs;
- the possibility for more “painless” repair and reconstruction of underground structures by placing them at a greater depth;
- the need to eliminate the environmental crisis in a complex system of “rock mass – technology – underground structure – environment”.

The upper tier of the underground space of cities is a chaotically branched network of utilities, where sewage and heating systems and other communications are located without taking into account possible emergency releases to nearby water bodies. About 1500 tons of oil products, at least 500 tons of salts of heavy metals and more than 22 000 tons of organic pollutants are discharged into the Moscow reservoirs annually, bypassing the treatment facilities. Thus, despite the ability of the natural ecosystem to ensure self-purification and balance, the Moscow region can become an ecological disaster zone in the coming decades. Therefore, the development of a new approach to the placement of underground structures and new environmentally friendly technologies and methods of their construction is extremely relevant.

Sustainable construction

From the standpoint of environmental safety, the most acceptable technologies can be justified only with a comprehensive approach to all aspects of the development of the city’s underground space, which includes:

1. Improving the quality of engineering-geological surveys of the subsoil for underground construction, followed by taking into account their results in the design and development of solutions to ensure the stability, reliability, durability of underground facilities and water resistance of their supporting structures. It is necessary:

- to substantiate the environmental compatibility of the technologies with the changing nature of the interaction between the elements of PTGS;
- to combine the high technologies and ways of strengthening the rock mass with the aim of increasing the rate of penetration of workings;
- to ensure computer modelling and calculation of parameters of technical and technological solutions based on a comprehensive assessment of the properties of rock mass and their compliance with the properties of the lining;
- to ensure complex consideration of the main factors characterising the current state of the system “rock mass – technology – underground structure – environment”; to identify the optimal combination of the parameters characterising the state of the system as safe;

2. Expansion of underground infrastructure and construction of new generation underground facilities.

3. Increasing the durability of underground structures based on the use of modern knowledge of rock mechanics, geomechanics, environmental aspects of the development of the underground space of the city, construction geotechnology.

4. Risk reduction in underground construction based on the analysis of risk situations in the natural and technical geosystem "rock mass – technology – underground structure – environment" and the forecast of changes in the environmental situation in general when using a particular technology of work.

An integral part of the processes that create conditions for sustainable development is the “sustainable construction”, including the underground one. This concept appeared relatively recently, and at the first International conference “Construction and environment” (USA, 1994) it was formulated as follows: “Sustainable construction means the creation and responsible maintenance of a healthy artificial environment based on the effective use of natural resources and environmental principles”.

Geo-ecological modelling

The basic environmental principles and concepts that form the basis of the concept of sustainable, environmentally safe underground construction can be formulated as follows:

- minimisation of negative impacts (pollution, excessive noise, vibration, electromagnetic fields, etc.) on natural ecological systems and natural landscapes at all stages of functioning of the natural and technical geosystem "rock mass – technology – underground structure – environment»;
- restoration and maintenance of biodiversity in construction and urban areas;
- the use of environmentally friendly architectural and planning solutions of underground structures; ecological reconstruction of the urban environment; attention to the aesthetic component of the urban complex;
- application of environmentally friendly building materials and underground construction technologies;
- construction of underground facilities in accordance with "high" technologies;
- making underground structures food-grade, biodegradable properties that allow them to blend and clean up the environment; create a healthy artificial habitat;
- waste reduction in underground construction;

- reclamation of the territories disturbed during the creation of the construction site and conducting works in the open way;
- the use of environmentally friendly man-made raw materials for the manufacture of building materials and products;
- implementation of environmental monitoring systems for underground construction at all stages of the life cycle of the underground facility;
- comprehensive and highly effective environmental control of technological decisions at all stages of the life cycle of the underground facility (environmental support).

In addition, the most important conditions for sustainable underground construction, compatible with the environment, are:

- recognition of the presumption of ecological danger of any planned activity on the development of underground spaces of the city;
- improvement of the regulatory framework to ensure sustainable and environmentally sound underground construction;
- organisation and development of a system of continuous environmental training for decision - makers in the field of underground construction;
- participation of scientific, design, public and other associations in solving problems related to the planned activities for the development of underground space.

A structural geo-ecological model of natural and technical geosystem "underground construction – the environment" is shown in fig. 1.

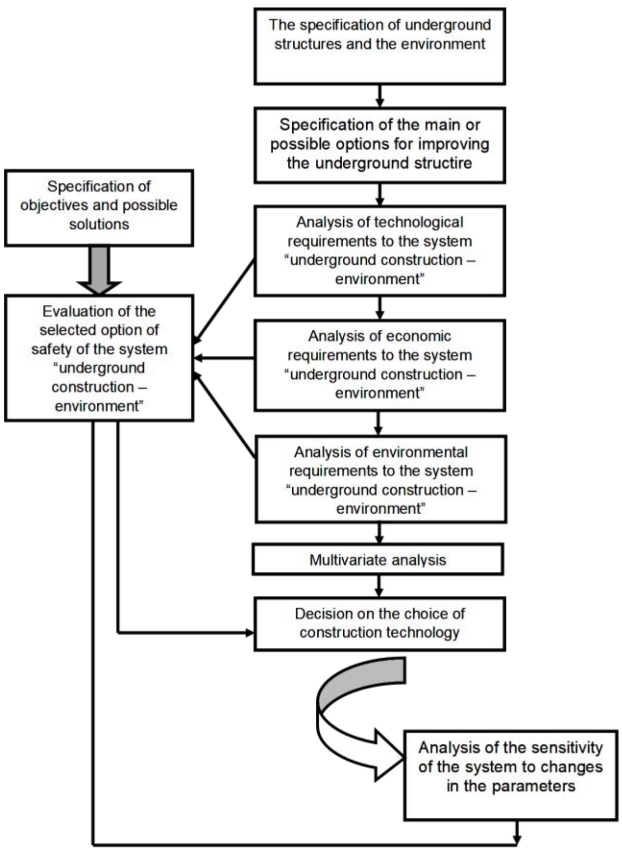

Fig. 1. Structural geo-ecological model

The choice of strategy and tactics for the implementation of sustainable underground construction is a very difficult task, requiring joint creative work of designers and builders, as well as specialists of other services, primarily environmental. All this places high demands on the level of professional training of future mining engineers in the field of environmental knowledge.

Conclusion

The formation of geo-ecological models of objects of underground construction on the basis of criteria of reliability and technological risk tolerance will allow to obtain the following results:

● Creation of theoretical developments to substantiate the mechanism of environmental and technological reliability of urban underground structures;

● Geo-environmental and geotechnical rationale for the choice of strategic directions for the development of the underground space of cities under the current and future level of development of science, techniques and technologies of underground construction;

● Modelling of parameters of geological and technological reliability on the basis of admissible risks criteria and safety of natural and technical geosystem (Fig. 1).

The results will shed some light on modern approaches related to the design of underground structures in large cities, seek innovative potential of environmentally friendly technologies for the construction of urban underground structures, and ensure environmental sustainability in the development of underground space of megacities.

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