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Methodology for Assessing Sustainability Resource of Ecological and Geotechnical Systems of Urbanized and Industrial Territories

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ABSTRACT

Under the sustainability resource to external influences is understood the ability of the geological environment to maintain its basic geotechnical properties within acceptable or specified limits. Environmental changes, being important accompanying ones, can also be limiting for engineering activities in case of unacceptable changes in engineering-geological and hydrogeological conditions.
The practice of construction in various engineering and geological conditions in Ukraine is replete with examples of negative consequences due to underestimation of the sustainability resource of natural and man-made systems. For example, deformations of the soil base were often observed during the construction of crushed stone pads for foundations on subsiding soils (the cities of Dnipro, Zaporizhzhia, Kharkiv); excessive rise in the level of groundwater in the built-up areas, which arose if poorly permeable soils were not removed before sanding (Kharkiv, Poltava); uplift of a shallow metro station associated with a sharp rise in groundwater levels (Kharkiv); precipitation and surface failures over underground workings (Donbas, Kharkiv), etc. Hence, there is a need to develop methodological methods for optimizing design solutions during construction in complex engineering and geological conditions. Our experience of several decades of engineering surveys for construction in regions with different natural conditions leads to the conviction that the concept of "sustainability resource to external influences" is universal and can be used not only to assess geotechnical risks, but also for geoecological forecasts in urban or industrial agglomerations: the state of the engineering-geological environment with underground structures, the upper part of the underground hydrosphere of cities, the development of exogenous processes, and so on. Maps of resources for the sustainability of territories can be used to solve specific problems of economic development and assess the consequences of anthropogenic impacts. A scheme for the implementation of design and survey work is proposed, taking into account integrated geotechnical and environmental assessments.

Keywords: sustainability resource, ecological and geotechnical systems, surveys, design

1. INTRODUCTION

From mechanics and cybernetics it has long been known that the more complex the system, the faster it breaks down, the larger the structure, the more vulnerable it is. This applies, first of all, to complex natural and man-made geosystems of urbanized and industrial territories. And most importantly, the decisions made in the past and the projects implemented can cause negative geoecological processes and it is often impossible to quickly correct the current negative consequences, that is, there is no possibility of quick response to problems.

However, geotechnical engineers are primarily involved in the design of foundations for public and civil buildings, and not all projects require environmental projections. Up to 90% of the objects in the design process of which these engineers are involved do not require mathematical processing or computer analysis; they mainly use previous experience (Chen, F.H., 2000). On the other hand, ecologists, who, as a rule, do not have a technical education, often have a vague idea of the degree of influence of various types of geotechnical, construction, and economic activities on soil and hydrogeological conditions and are unable to assess the environmental consequences of certain design decisions comprehensively. The project "Assessment of impact on the environment" section is

either absent or is carried out formally. As a result, the implementation of projects that are geotechnically correct in the sum often leads to unforeseen environmental consequences in vast urban and industrial areas, as well as, paradoxically, to geotechnical accidents.

In modern conditions of rapid development and anthropogenic transformations of the natural environment, the signs of environmental crises in cities and industrial areas have become especially noticeable, due to hidden factors of technogenic geological processes, the negative consequences of which were not taken into account earlier in traditional methods of surveying, designing, building technology, industrial facilities, and their operation (Utenov, E.S. et all, 2017). The methodological approaches we propose allow us to choose one of two objectively existing strategies: prevention of negative impacts or protection from them. Naturally, the implementation of protective measures should be carried out if it is impossible to prevent natural disasters (seismic processes, extreme climatic events such as floods, hurricanes, etc.) - we must be prepared for them and take protective measures. If it is possible to predict the negative consequences of engineering activities, then it is necessary to control this activity and prevent such consequences.

2. ISSUES OF THE METHODOLOGY OF DESIGN AND SURVEY WORK IN URBAN AREAS

The main issues facing engineers-geologists, geotechnicians and ecologists during surveys in urban and industrial areas, as well as possible ways to solve forecasting problems, were identified in the article (Strizhelchik, G., 1987). Based on the published results of our previous works (Iegupov, V., et all, 2018), (Iegupov, V., Strizhelchik, G., 2021), (Iegupov, V., et all, 2021), we believe that the greatest attention should be given to the issues of sustainable development of urban areas in general and harmonization with the natural geological environment, as well as the georisks of hazardous natural and man-made engineering-geological processes (Iegupov, V., Strizhelchik, G., 2022).

Modern publications on engineering-geological processes in urban areas include studies of landslide activation in comparison with non-built-up lands in various natural zones (Johnston, E. C., et all, 2021), (Li, G., et all, 2017); assessment of risks associated with increased precipitation intensity due to global climate change (Kirchmeier-Young, M. C., & Zhang, X., 2020), (Li, C., et all, 2020), dangerous floods and a sharp rise in groundwater levels (Sanderson, B. M., et all, 2019), (Chebanov O., Zadniprovska A., 2011).

In general, research on this topic presents:

- theoretical and practical measurements of local agglomerations with the natural environment;
- consequences of the technogenic impact on soils and groundwater;
- activation of dangerous engineering-geological processes as a result of the technogenic impact.

It should be noted that the issues of the methodology of engineering and geological surveys, the possibility of obtaining complete and reliable information for making reliable and safe urban planning, and engineering and economic decisions are not covered enough.

The need to adjust the methodology for making design decisions is caused by numerous cases of negative environmental consequences associated with construction activity. These consequences are as follows:

- violations of surface runoff during development lead to the formation of new aquifers and flooding of territories with groundwater and perched water (the cities of Dnipro, Zaporizhzhia, Kharkiv);
- surface subsidence and dips are not uncommon in places where beams and ravines are filled with loose soil, construction garbage, and household waste;
- the suffusion processes occurs during underground construction in unstable soils, as well as in the development of underground mineral deposits (Donbass);
- deforestation on the slopes contributes to the occurrence of floods and mudflows (Carpathian mountains);
- reduction of the cross-section of the aquifer due to the installation of a pile field, a cement curtain, as well as a metro tunnel, leads to the appearance of a barrage effect and flooding of the territory (Kyiv, Kharkiv);

- the screening effect of building, asphalt, and concrete coatings causes a decrease in the natural evaporation of ground moisture and the accumulation of condensation water under foundations, dampness in basements;
- systematic or emergency leaks from water networks cause an increase in GWL or the formation of man-made aquifers, as a result - a change in the properties of foundation soils, subsidence of soils and deformation of building structures, as well as flooding of underground parts of buildings and structures;
- thixotropic liquefaction of soils under vibration exposure leads to the creation of emergency situations in surface and underground construction;
- lift up of a shallow metro station associated with a sharp rise in the groundwater level (Kharkiv) (Iegupov, V., et all, 2018);
- swelling and shrinkage of clay soils in places of emergency or periodic soaking and subsequent deformations of soils and building structures;
- soil displacements during underground tunnels can lead to surface subsidence, failures, and deformations of buildings located near the tunnels under construction and in operation (Fig. 1 left).
- landslides and collapses are often caused by cutting steep slopes that have an insufficient margin of stability; also, intensification of landslide processes takes place during the arrangement of centralized water supply in the absence of water disposal (Izyum, Krasnograd, Kupyansk, Pervomaisk, Mariupol, Melekino) (Fig. 1 right).



Figure 1. *Building with a deformed wall as a result of soil settlement in the area of the metro tunnel, in Kharkiv (left). Cracks on a landslide slope and displaced houses in Melekino (right)*

All of the above events took place in real situations in the urbanized and industrial territories of Ukraine. Naturally, in each case there were reasons, but all of them are united by the fact of lack or simply the absence of high-quality survey information, the lack of forecasting, and the underestimation of the environmental consequences of engineering activities.

3. EXAMPLES OF NEGATIVE ENVIRONMENTAL CONSEQUENCES OF MINING ACTIVITIES

Particularly intense negative manifestations of engineering and geological processes that affect the ecology of territories take place during mining activities, the extraction of various minerals, and the construction of underground structures (mines, tunnels, etc.).

Let us give some specific examples of negative environmental consequences as a result of the operation of mining enterprises, as well as geotechnical activities in the industrial territories of Ukraine. During the exploitation of the New Carthaginian rock salt deposit (Donetsk region) by the method of underground dissolution, the most significant negative factor in the impact on the environment, including the subsoil, was the subsidence of the earth's surface as a result of the dissolution of salt layers, the extraction of brine and subsequent later displacements of overlying rocks into the worked-out spaces. Fig. 2 shows the largest surface subsidence in the eastern part of the site in the zone of maximum extraction of salt reserves.



Figure 2. *Surface subsidence troughs at the New Carthaginian rock salt deposit*

The first recorded movement of rocks in the North-Western section of the deposit, accompanied by the formation of a subsidence trough on the surface of the earth with a size of 250x275 m and a depth in the center of 8.6 m, occurred in 1977; the second trough, 225x250 m in size and 8.3 m deep, was formed in 1980. Currently, subsidence of the earth's surface covers more than half of the territory of the North-West area. The maximum depth of troughs, according to mine surveying observations, is more than 20 m. At the bottom of large troughs, fresh lakes have formed due to atmospheric precipitation.

Subsidence of the earth's surface is an inevitable consequence of the development of the field, given the depth of rock salt beds (200 - 230 m) and very significant volumes of its extraction from a small area Dips of the earth's surface of various shapes and depths often occur above shallow underground mine workings. Fig. 3 (left) shows sinkholes over abandoned gypsum mines in the area of the Stryapovka beam, Donetsk region. Fig.3 (right) - smoking waste heaps in the Horlivka region, Donetsk region can serve as an illustration of contamination of both soil and atmospheric air.



Figure 3. *The area above the abandoned gypsum mines near the Stryapovka beam, Donetsk region (left). Smoking heaps near Horlivka, Donetsk region (right)*

Obviously, the use of such territories for agricultural or construction purposes is practically impossible.

Another typical example is the storage pond of the Samsonovsky mining and processing plant, in the Luhansk region. Here, coal mining waste (sludge) is dumped into a natural pond and a “black beach” is formed. Over time, it ignites spontaneously and transforms into a "burnt beach" (Fig. 4).





Figure 4. *"Black beach" from coal mining waste (left). Funnel on the "burnt beach» (right), Samsonovsky mining and processing plant, Luhansk region (right)*

"Burnt beach" - an area of over 500 m^2, composed of red-brown burnt rock with sintered slag. The surface of this area sank 0.5 m below the surface of the unburned sludge located closer to the water's surface. Funnels formed by outgoing gases - combustion products are clearly visible. Trees and stumps here were burned from below, which indicates the underground location of the centers of spontaneous combustion of the sludge. The depth of distribution of the burnt rock is limited by the upper boundary of the capillary fringe of the filtration flow from the reservoir. During the combustion of coal particles, the smallest - dusty and clay particles are sintered and large formations appear, similar in composition to ceramics.

4. METHODOLOGICAL PROBLEMS

Unfortunately, the current rules and regulations are mainly focused on the technical and economic efficiency of construction projects and mining enterprises. This is certainly necessary, but along with this, it is imperative to study and evaluate possible environmental consequences. Currently, technical and environmental requirements are not methodologically linked and, as a result, negative problems often arise, since the consequences of poor-quality decisions do not appear immediately, but over time, as environmentally significant events accumulate.

Participation of expertise in the current situation in Ukraine is to control compliance with building codes, legislation, and by-laws, which, of course, cannot largely solve the problem of negative environmental consequences.

In our opinion, the key questions are:

- insufficient scientific understanding of cause-and-effect relationships between engineering-geological and environmental processes and phenomena in urban, industrial construction, and mining activities;
- the narrow focus of existing building codes and regulations, which does not take into account a number of consequences from the point of view of geoecology;
- weak professional control over the quality of design solutions;
- unreasonable minimization of costs for survey, design, and construction work.

The question arises about the possibility of a way out of this situation. We see this opportunity in the implementation of the principles that should be enshrined in regulatory documents. It is necessary to introduce requirements for the development and verification of forecasts into the practice of surveys. To make an examination of survey materials obligatory for any objects. Moreover, experts must be sufficiently qualified and independent.

A schematic diagram of the organization of design, survey, and construction work is shown in fig. 5. Environmental assessments of construction or other economic activities should be given at all stages, from planning (preliminary environmental risk assessment), then during the survey process.

Construction work is carried out only after a comprehensive geo-ecological examination. Integrated geotechnical and environmental monitoring should be carried out during the construction and operation of facilities.

The organizational structure reflected in the block diagram meets the requirements of modern standards adopted in Ukraine. The composition and content of complex engineering-geological, geotechnical surveys, as well as surveys for the rational use of the environment are detailed in DBN A.2.1.-1-2014 "Engineering Surveys for Construction". Rejection or reduction in the quality of survey results, and, as a result, the adoption of insufficiently substantiated design decisions is usually associated with a low rate of control, including expert control. So far, the effectiveness of our proposals can only be assessed qualitatively: by such assessments as “more reliable”, “more secure” and the like.

With a reasonable assessment of the environmental significance of various geotechnical measures, it follows logically that the industrialization of geotechnical and construction activities in the context of urbanization should be accompanied by a systematic analysis of the consequences and risk assessments of the exit of natural systems from an ecologically acceptable state. To do this, earlier (Strizhelchik, G., 1987, Iegupov, V., Strizhelchik, G., 2021). we proposed the “sustainability resource to external influences/impacts” concept.

Under the resource of stability we mean the ability of the system, under external influence, to maintain its appearance and functional properties within acceptable limits.

For example, the resistance resource of loess macroporous soil to additional settlement during soaking, i.e. drawdown will be equal to 0.03 - 0.07 MPa in the south of Ukraine and 0.09 - 0.17 MPa in the northeast. With this in mind, it is possible to provide appropriate methods for preparing the soil base during the construction of foundations (complete cutting of the subsiding thickness, tamping, pressure reduction under the base of the designed foundation, cementation, silicification, etc.).

The resource of resistance to additional infiltration is determined by the amount of water that infiltrates into the ground aquifer to raise the groundwater level above a certain depth from the day surface (most often - 2-1 m), or a normalized depth below the base of the foundations (usually not closer than 0.5 m).

A more complex case in determining and taking into account the stability resource of a landslide-prone slope. A number of factors act here: an increase in mass during soil soaking or when building up in the zone of shear stress formation, a decrease in resistance during cutting or flushed by river or sea in the zone of retaining stresses. Here it is necessary to be guided by specific variants of planned (or predicted) impacts based on special methods.

Methodically, the basis for zoning the economic development (or reconstruction) of territories in terms of "resource of resistance to external influences" should be built on the principles of the most developed geotechnical zoning. The differentiation of territories into separate regions should also contain data sufficient to assess the state of the main indicators of the ecosystem. These data can be used to assess the reaction of the geological environment to the technogenic impact, the occurrence of dangerous exogenous processes.

An example of a practical assessment of the resource of stability of the territories of a large city to the most significant external influences is the scheme we developed for the city of Kharkiv (Iegupov, V., Strizhelchik, G., 2021). Compiled on the basis of geomorphological, and hydrogeological conditions of the territory, taking into account our many years of experience in engineering surveys for construction. This scheme reflects the georisks associated with the activation of dangerous slope processes (landslides, erosion, erosion of soils and underlying soils), with excessive water infiltration: groundwater flooding and surface water flooding.

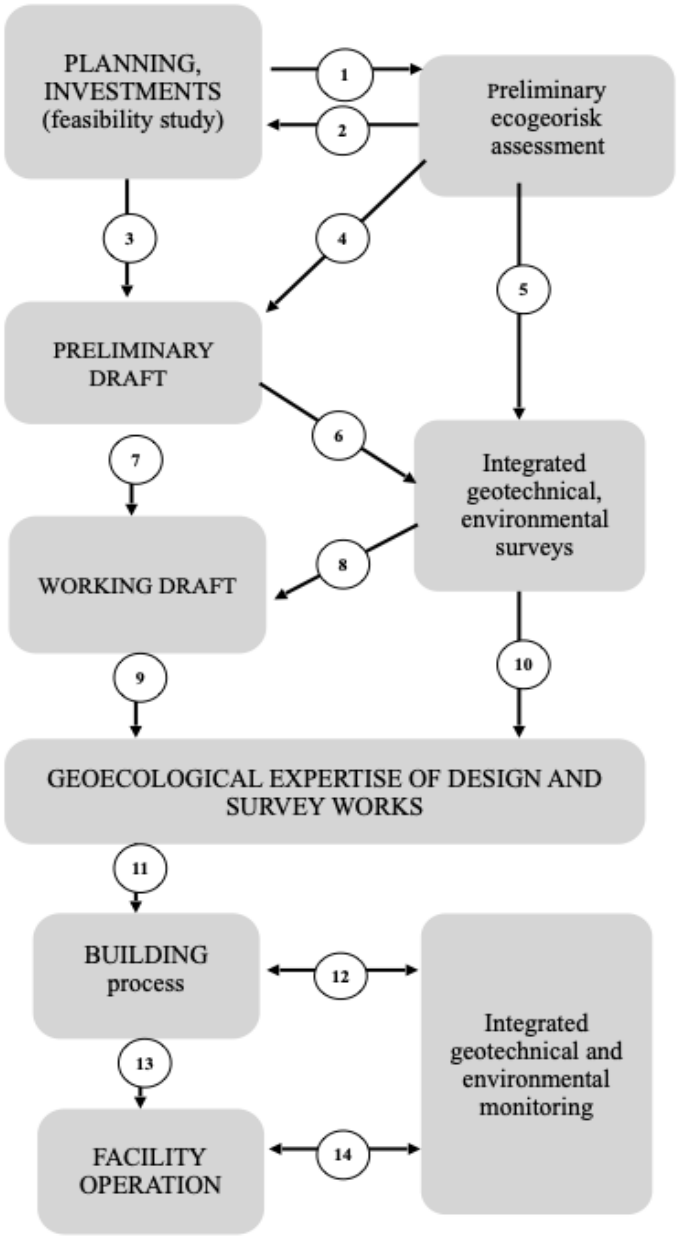

Figure 5. *Recommended scheme for organizing the construction preparation process:*
1 - the customer's appeal to a specialized expert organization;
2 - conclusion on the possibility and feasibility of construction, taking into account environmental and geological risks;
3 - order for design;
4 - recommendations of specialists for the future project;
5 - recommendations of specialists for the performance of survey work (geological engineering, hydrogeological, geotechnical, environmental and other necessary surveys);
6 - the task of conducting the necessary surveys;
7 - assignment for the preparation of a working draft;
8 - technical reports on all types of survey work performed;
9, 10 - presentation of the results of design and survey work for geoecological expertise;
11 - assignment for the construction of the final project, taking into account the results of the examination;
12 - control during construction;
13 - putting the facility into operation;
14 - control during operation.

5. ISSUES OF PRACTICAL APPLICATION IN GEOTECHNICS

The ecological and geotechnical system of an urbanized area (considered construction and/or monitoring site) is a rather complex system, therefore, in order to analyze its state, and, as a result, assess the sustainability resource, it is necessary to divide it into a number of subsystems (elements) that are characterized by appropriate parameters.

In this case, under the assessment of the resource it is necessary to understand the assessment of the residual resource of the geotechnical system (the service life, which is of interest from a certain point in time), after the occurrence of violations of its state. The fundamental concept for calculating the residual life of complex systems is the principle of the safe operation of a particular system. According to this, the evaluation of the geotechnical system is carried out according to the parameters that ensure its reliable and safe operation in accordance with the design documentation, and the residual life is carried out according to the determining parameters of the technical condition.

In our opinion, in each case it is necessary to solve the following problems:

- selection of the determining parameter and ranking of factors influencing the state of the system, into primary and secondary ones (using calculations according to justified methods or by expert means);
- selection (creation) of a life cycle model specifically for a given geotechnical system, in which numerical reliability parameters are used as a criterion for the technical state of the system, which are a quantitative integral assessment of the technical state of the system;
- information about the statistical parameters of the factors affecting the system;
- a clear understanding of the stages of system degradation and a description of this process by a ratio that would take into account the relationship between the building and the foundation, the geotechnical category of complexity, the quality of operation, and the estimated service life of the building.

And in this case, one cannot do without the use of the modern theory of reliability of complex technical systems, which makes it possible to obtain a quantitative assessment of reliability and safety, as well as to determine the resource of the system.

A serious problem in the way of greening engineering activities is the training of specialists in the fields of both geotechnics and ecology. It should be recognized that modern technical education provides, to a greater extent, the development of fundamental laws, principles, and rules developed in the 19-20 centuries and does not at all reflect the problems that arise in the conditions of increasingly intensive modern urbanization, the use of underground space and the exploitation of subsoil. On the other hand, environmental education is mainly aimed at preserving biocenoses in a natural or acceptable state, which is certainly necessary but does not solve the problems we have raised.

6. CONCLUSION

Unprecedented modern changes in nature have already affected sea level rise, soil erosion, forest degradation, melting glaciers, and increased flooding. The main threat facing humanity is the ever-increasing destruction of ecosystems. Over the past few decades, there has been a constant and largely cumulative degradation of the global ecosystem due to the continued depletion of water sources, clean air, arable land and other natural resources.

Today's trends in urban planning associated with the intensive development of underground space (multi-story underground parking lots, subway tunnels, deep sewers, etc.) increase the intensity of anthropogenic impact on the geological environment.

In this regard, there is a need for more rational and resource-saving use of the geological environment of urban areas. This can be achieved through appropriate changes in regulatory documents and the mandatory organization of control over the quality of specific design and survey work, as well as engineering-geological and environmental control over the state of the environment of the urban area. Also, one of the control tools is the creation and use of models that describe the features of the system life cycle, with the help of which it is possible to predict and timely correct the state of the system.

Apparently, restrictions and regulation of environmental impacts are no longer enough today, and it is time to develop and implement the principles of effective synergistic interaction in the “man – environment” system.

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