Control of Environmental Safety in the Construction of Subway in Megapolis

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Abstract. It was noted that in the construction of subways, the achievement of planned indicators is possible with the use of innovative construction technologies, in particular of tunnel boring machine (TBM). The analysis of the factors that determine the negative impact on the environment when using the TBM is compared with civil construction. The scientific novelty and practical results is given. It was proposed to take into account the degree of attractiveness of the territory when deciding on the location of construction sites. An approach is proposed to determine the attractiveness of the territories for the construction of metro facilities. The task of managing environmental safety during the construction period has been formulated. The procedure for managing environmental safety in the construction of subway lines is given. It is shown that as criteria for making management decisions, indicators characterizing the degree of influence of the physicochemical nature on the state of the environment should be used. It is said that the most rational option for minimizing the negative impact on the OS should be considered as a complex implementation of measures, at which simultaneous reduction of several negative factors to achievable levels is achieved: noise and vibration effects, pollutants of various chemical nature entering the atmosphere, etc. The principles of environmental safety management during noise and vibration effects, as well as the disposal of soil and soils formed during the construction of metro facilities are substantiated.

1. Introduction
The solution of transport problems in modern megalopolises impossible to imagine without the use of underground transportation systems - subways. For example, in St. Petersburg, nowadays 45% of total passenger traffic is carried by the subway [1]. The increase the size of pedestrian accessibility zones of subway stations from the currently reached value of 35.9% of the compact planning area up to the acceptable value providing the city residents use of underground transport is associated with an increase in the operating length of subway lines up to 202.833 km with the introduction of new stations [1].

Achievements of planned targets in the construction of subways in megalopolises, including St. Petersburg city, are possible only with the use of innovative construction technologies, for example, tunnel boring machine (TBM) [2,3].
The use of TBM is characterized by a number of negative factors associated with the impact on the environment [4,5]. Contrary to the civil engineering facilities located on the surface, these factors include:

- significant duration of work, reaching a five-year period with a temporary change in the levels of negative impact;
- simultaneous operations underground and on the surface;
- air pollution by exhaust emissions from loading and delivering equipment, working in conjunction with the TBM, freight transport on construction sites and diesel power plants;
- pollution of groundwater;
- the need for additional definition of hazard class and subsequent disposal of waste generated during shield soil excavation [2];
- noise and vibration pollution of adjacent territories [6,7,8,9,10,11,12,13].

A number of studies are devoted to assessing the impact of construction of subway facilities [6–18]. The majority of these papers has an emphasis on the study of noise and vibration effects when using shield tunneling or piles installation to create a fence for pits for building vestibules of stations or TBM installation [6-13], and also on air pollution [14,15]. A much smaller number of papers are devoted to the justification of the strategy of handling the soils formed during the construction of subway facilities, depending on their class and hazard category [16,17]. There are basically no studies aimed at a comprehensive assessment of combined impact of all negative factors, especially considering the background values of their chemical and physical parameters. Among the papers having, at least partially, the above estimates, the study [15,18] should be noted.

The novelty of scientific provisions and practical results presented in this paper is to justify a comprehensive approach to determining the negative impact on environmental safety of natural and man-made factors that occur in the construction of subway facilities in St. Petersburg and subsequent development of measures for prevention their impact or minimize it to practically achievable values.

2. Statement of problem

Ensuring comfortable living for people while preserving the unique architectural buildings and monuments in the subway construction in St. Petersburg is impossible without addressing the issues of environmental safety [19].

Subway facilities built in areas with high population density can be located at different distances from settlement zones, ranging from hundreds to units of meters. In the first case, the impact of construction work on the environmental situation in residential areas will be basically absent and the total effect of negative impact will be determined only by the background values of existing factors.

When deciding on the location of construction sites, one should take into account the degree of territory attractiveness (the inverse value of ecosystem disturbance). Assessment of territory attractiveness can be made on the basis of ranking of negative impact for each factor considered and their cumulative influence. The higher is the ecosystem disturbance, the less attractive is the territory for the location of subway facilities.

A different situation arises in the case of immediate proximity of subway facilities constructed to the residential area. Here the impact on the environment determined by the background values is amplified due to the influence of technological processes and equipment used in construction.

Due to that, the main task of managing environmental safety during the construction period is to reduce the environmental impact of construction site to practically achievable levels, for which values determined by background factors can be taken.

3. Principles of environmental safety management in the subway construction

The procedure for controlling environmental safety in the construction of subway lines shall include the following actions:

- implementation of preliminary assessment of geo-ecological situation, which involves the identification of factors determined by the combined effect of initial physical and chemical...
fields formed in all elements of urban environment by the beginning of construction of subway facilities;

- assessment of environmental impact of technological processes that take place during the construction of subway facilities with the selection of the most significant factors;
- development of environmental measures to minimize the impact of these processes and their subsequent implementation;
- mine and ecologic monitoring of the environment with the establishment of actual values of negative factors;
- adjustment of ecologic protection measures based on the results of mine and ecologic monitoring.

In the above-described control system, the mountain and ecologic monitoring is essentially a feedback channel, which is used to transmit information necessary to increase the effectiveness of measures to reduce the man-made load on the environment.

Criteria for making management decisions should be indicators characterizing the degree of influence of factors of a physical and chemical nature (concentrations of pollutants in atmospheric air, equivalent levels of vibration noise), as well as the content in soils planned for development of heavy metals and organic toxicants.

4. Preliminary assessment of the geo-ecologic situation in the locations of subway facilities in St. Petersburg

Preliminary assessment of the geo-ecologic situation should be carried out on the background values of air pollution, noise and vibration pollution, as well as the degree of soil contamination. One of the possibilities for comparing the baseline pollution values of territories chosen for construction is the use of a point-based system, in which each category of considered pollution factors (for example, permissible, moderately dangerous, dangerous and extremely dangerous categories) are assigned with corresponding score values from 1 to 4. Determination of pollution category for each factor is carried out on maximum and minimum values recorded in the process of environmental engineering survey.

For example, it is proposed to establish background levels of air pollution on the basis of index air pollution (IAP), the value of which varies between 0 and 7.5 [20]. When IAP = 0–2.5 the air pollution degree corresponds to the clean atmosphere, and when IAP = 2.5 – 7.5 — it corresponds to the slightly polluted atmosphere. It can be assumed that the category of clean atmosphere corresponds to the category “permissible”, and the category of slightly polluted atmosphere to the category “moderately dangerous”.

As an indicator characterizing the degree of noise and vibration pollution, it is advisable to take the ratio of actually registered equivalent noise levels (vibrations) \( L_{eq} \) to the standard \( L_a \), i.e.

\[
N_{eq} = \frac{L_{eq}}{L_a}
\]  

When this ratio is 1-1.5, the noise (vibration) pollution can be assumed as “permissible”, \( N_{eq} = 1.5-2 \) — it is “moderately dangerous”, \( N_{eq} = 2-3 \) — it is “dangerous”, and \( N_{eq} \) more than 3 — “extremely dangerous”.

To assess the unfavorable effect of radiation, it is advisable to use the distribution density of radioactively contaminated sites (DD RCS) which can vary, according to the Russian Geo-ecological Center in St. Petersburg, from 50 rcs/km² to almost zero [21]. Using our proposed approach, we define a admissible category corresponding to the values of distribution density for DD RCS equal to 0–2 rcs/km², “moderately dangerous”, DD RCS 2–5 rcs/km², “dangerous”, DD RCS 5–10 rcs/km², “extremely dangerous”, DD RCS > 10 rcs/km² and more.

The degree of soil contamination in areas of the proposed construction of subway facilities depending on the concentration of heavy metals and organic toxicants is estimated by the degree of soil contamination planned for development by \( Z_c \) [22,23].
When the total value of $Z_c$ is less than 16, the soil is referred to as “permissible” category of pollution, 16-32 — as “moderately dangerous”, 32-128 — as “dangerous”, more than 128 — as “extremely dangerous” category of pollution [22].

The integral assessment of ecosystem disturbance is carried out by summing up the scores for each of the factors.

Thus, the safe condition of “permissible” disturbance of the ecosystem corresponds to 5 points, “moderately dangerous” disturbance — 6-10 points, “dangerous” disturbance — 11-15 points, “extremely dangerous” disturbance — 12-20 points.

5. Environmental safety management during construction

The main factors determining environmental safety in the construction of subway facilities are as follows: noise pollution, vibration impact on the foundations of residential buildings and developed soil and subsoil.

Based on the computational analysis and experimental studies performed during the period of mine and ecologic monitoring, it was established that the control of environmental safety under noise exposure of the facilities under construction should be comprehensive, involving installation of a fence having the required height ensuring standard noise values at the area adjacent to the construction site, and the use of noise protection glazing of window openings of apartments located on the second and subsequent floors, which makes it possible to reduce to the required values the noise levels directly in the residential premises [11].

To develop effective measures for reduction of vibration impact during shield tunneling, it is necessary to ensure, first of all, reliable information about the geological structure of soil massif. In this case, in areas where the presence of rock inclusions with high strength is predicted, it is advisable to use measures that minimize vibration impact on the foundations of houses located in the 40-meter zone, for example, screens of various designs, built in soils along the tunnels route.

One of the central issues in the development of chemically and radioactively contaminated soils that correspond to dangerous and extremely dangerous categories [17] is the choice of a strategy for placing the soil after its extraction to the surface. The solution to this problem is possible only in the case of a detailed study of areas that, according to preliminary analysis, have previously been subjected to significant man-made pollution.

However, the final conclusion about the class of danger of the soil and, accordingly, about the places of its subsequent placement or disposal can be made only in the process of monitoring the pollution of excavated soils [24].

6. Conclusion

The peculiarity of formation of the environmental situation in the construction of subway facilities in megalopolises is a combination of unfavorable background environmental parameters associated with the influence of negative natural and man-made factors determined by the geological conditions and the impact of urban infrastructure (emissions of pollutants from various industries and transport, traffic noise and vibration, soil contamination caused by waste disposal in the previous period of city existence) and near environmental impact of equipment and technological processes used in the construction process.

The preliminary assessment of geo-ecological situation essentially represents the organizational stage of environmental safety management which allows to reduce the cost of measures for elimination of environmental negative impact due to preliminary selection of construction site with minimal environmental disruption at the construction stage.

The main task of managing environmental safety during the construction period is to reduce the environmental impact of construction site to practically achievable levels, for which values determined by background factors can be taken.
In the environmental safety control system, the mine and ecologic monitoring is essentially a feedback channel, which is used to transmit information necessary to increase the effectiveness of measures to reduce the man-made load on the environment.

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