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3D NOISE MODELING AND ASSESSMENT IN THE DESIGN OF RESIDENTIAL AREAS

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Abstract: *Three-dimensional maps showing acoustic exposure can be used as information basis for residential areas planning and design in cities. This research work focuses on estimating changes in acoustic pollution in a large city caused by a new residential quarter being built there; overall, the quarter will be made up of 28 buildings including a school and a trade and entertaining center. The highest buildings in the quarter should not exceed 25 floors. Calculated estimates were performed at various heights, starting from 1.5 meters and up to 75 meters above the ground. Calculation results obtained for various heights allowed building up a three-dimensional exposure picture for assessing expected levels of external noise at each floor in an apartment block. All calculations were made and acoustic exposure was visualized with a geoinformation system (ArcGIS 9.3 with ArcScene module) that allowed showing geographic and attributive data concerning an examined territory. Our experience and methodical approaches to estimating and visualizing noise propagation will allow making well-grounded managerial decisions on city development. Noise factor assessment is a key element in creating a favorable living environment in a city.*

Keywords: *acoustic calculation, geoinformation systems, three-dimension picture*

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1. INTRODUCTION

Over the last years there have hardly been any changes in a share of health disorders caused by exposure to physical factors, noise included. As per data obtained from the State Report "On sanitary-epidemiologic welfare of the population in the RF in 2019" a specific weight of noise levels deviating from sanitary standards accounted for 13.4% among non-ionizing physical factors whereas a considerable part of residential areas in large cities in the RF is located in zones with acoustic discomfort. Besides, noise has been and still remains a prevailing non-ionizing physical factor when it comes down to people's complaints as its share amounts to 66.8% [1].

At present large cities and megacities are developing so rapidly that it requires thorough planning as regards residential areas and other zones, transport infrastructure development, and paying greater attention to other important issues related to providing a favorable living environment for city population [2,3,4,5].

Noise maps created for a settlement can be used as a tool for residential areas planning and design in cities as they provide quite an informative picture of the current situation and make future prospects easier to obtain and more reliable [6,7]. Several scientific works that focus on describing acoustic environment and present research results on specifically designed maps contain a mechanism for collecting, analyzing and processing data necessary for creating strategic maps showing noise exposure [8].

Issues related to acoustic waves propagation are rather vital due to a situation when apartment blocks with different number of floors are being built in the same area and it frequently requires estimating and fixing certain limits on a number of floors in a building. Such issues can be resolved only when a three-dimensional picture showing acoustic modeling is applied [9,10].

Our research goal was to perform comparative hygienic assessment of acoustic situation in a central part of a large city, both its current state and future prospects related to a new residential quarter being built there at the moment. This construction will necessarily involve changes in transport infrastructure on a considerable territory. The work has been accomplished taking into account all accumulated data and knowledge on acoustic modeling in densely populated urban areas and aims at using acoustic calculation results when managerial decisions on construction are made and when project documentation is developed as it will allow providing more favorable living environment in a city.

2. DATA AND METHODS

2.1. Hygienic assessment tools

Our research object was a new construction site with its overall territory being equal to 30 Ha located in Perm, a large industrial city with its overall population exceeding 1 million people. The construction site was planned for a new residential quarter.

The examined territory was located next to large city motorways (Geroev Khasana street, Chkalova street, and Chernyishevskogo street), and it created an overall acoustic picture on the territory where a new residential quarter was being built and in the closest residential areas as well. When performing acoustic modeling, we took into account such basic noise sources as traffic network sections (hereinafter – TNS) included into the motorways mentioned above and gave equivalent noise level for each section which was calculated taking into account actual traffic intensity, road surface quality, and allowed speed on the motorways. Initial data on traffic intensity were provided by the Municipal Traffic Management Office in Perm, and other reference information was obtained from public sources. We calculated acoustic characteristics of each TNS using available procedures on calculating equivalent noise levels produced by traffic. To perform actual modeling, we created and used a database on 2 thousand noise sources (hereinafter NS); approximately 80 out of them (TNS actually) were located on the examined territory and the rest created background noise pollution.

Average daily traffic intensity on the examined motorways reached 965 vehicles per hour (Chkalova street). In rush hours in the morning and evening traffic intensity amounted to 2,430 and 2,670 vehicles per hour accordingly but it was only short-term. Acoustic properties calculated for the motorways were as follows (according to traffic intensity): average daily equivalent noise level was equal to 71.2 dBA; in morning rush hours, 75.2 dBA; and in evening rush hours, 75.6 dBA. Average traffic intensity for Geroev Khasana street amounted to 609 vehicles per hour so average daily equivalent noise level amounted to 69.2 dBA there whereas average daily traffic intensity on Chernyishevskogo street amounted to 438 vehicles per hour and average daily noise level there amounted to 67.8 dBA.

According to construction plans approximately 12 new streets and passages would appear on the examined territory (approximately 40 TNS or new noise sources). We took traffic intensity for these new streets and passages to be equal to 20% from actual traffic intensity on the neighboring motorways, namely average daily traffic intensity was assumed to vary from 131 to 248 vehicles per hour and it corresponded to equivalent noise level varying from 59.0 to 61.8 dBA accordingly.

Acoustic calculations were made with "Ecolog-Shum" program software (version 2.4) with built-in algorithms and procedures for estimating noise propagation over a territory fixed by the Russian state regulatory methodical documents. When creating models, we took into account screening elements preventing noise waves from spreading such as capital construction objects located on the examined territory.

Initials data and acoustic calculation results were visualized with ArcGIS 9.3 program software. Each group of data on noise exposure sources, screening elements, and other components included into acoustic modeling was characterized with attributive data on an object occurring on a vector map showing the examined territory. Attributive data on objects included into modeling scope contained information on parametric and acoustic properties of noise sources, heights spotted on the examined buildings and contractions in the city, parameters of calculation points and areas and other information that was necessary for determining location and characterizing an object under consideration on the examined territory.

A three-dimensional spatial map showing acoustic calculations results was built with ArcScene module.

2.2. Structure of data applied in the research

To perform modeling within the present research work, we applied the following data:

- data on mobile sources of noise exposure on Perm city territory. Overall, more than 1,300 TNS are located in the city. In our research we considered approximately 80 TNS located close to the examined territory and exerting their influence on it;
- data on capital construction objects on Perm city territory. Overall, more than 130,000 objects are located in the city that can be considered screening elements. In our research we took into account approximately 700 buildings and constructions located on the perimeter of the examined territory.

Basic maps for creating a three-dimensional spatial map were the following:

- a vector map showing Perm city territory with a set of electronic layers, its format being *.shp, with spatial objects located in the city given in electronic form with relevant attributive information;
- bit-image maps showing the examined territory obtained as per data contained on a public cadastral map made by the Federal Service for State Registration, Cadastres, and Cartography (https://pkk5.rosreestr.ru/);
- Google Earth. This data source is a set of the Earth surface images made from the space with various digital processing and in different time periods (http://www.google.ru/intl/ru/earth/);
- reference cartography data;
- cartographic materials with visualized project decisions on locating capital construction objects on the examined territory.

Our research involved overlapping bit-image maps and vector data on the examined territory and it allowed us to estimate the existing situation and determine zones with acoustic discomfort as well as locate zones that were acoustically quiet using acoustic calculations in order to resolve issues related to housing construction as well as a wide range of other issues.

The examined residential quarter (RQ) "Arsenal" is located in "Krasnye Kazarmy" residential area with its boundaries being Geroev Khasana street, Chernyishevskogo street, Egoshikha river, and Chkalova street. The area with its total square being 30 Ha is located in the city center with its part directly neighboring with Egoshikha river.

Overall, the residential area should include several buildings with different number of floors:

- 13 apartment blocks, 25 floors each;
- 2 apartment blocks, 19 floors each;
- 1 apartment block, 14 floors;
- 5 apartment blocks, 12 floors each;
- 2 apartment blocks, 9 floors each;
- 3 apartment blocks, 8 floors each;
- 1 trade and entertainment center (TEC), 6 floors;
- 1 school, 3 floors.

Fig. 1: A scheme showing apartment blocks location within "Arsenal" residential quarter

When "Arsenal" RQ was designed and construction works started, there were no streets or motorways on that area. Entry/exit passage was only an intra-quarter one going from Chernyishevskogo street and Karla Marksa square.

The new RQ is going to include 3 new streets (Vilgelma de Gennina street, Vasiliya Tatischeva street, and Karla Moderakha street), 12 new passages and roads; the existing transport infrastructure is going to be reconstructed as well:

– the existing passage onto Chernyishevskogo street going from Karla Marksa square (a section in Vilgelma de Gennina street) will be reconstructed;
– a new exit passage will be built, going onto Chkalova street as continuation of Nikolaya Vorontsova street (former railways);
– a new exit passage will be built onto Geroev Khasana street as continuation of Vasiliya Tatischeva street (going together with Solovyiova street);
– a new exit passage will be built onto Chernyishevskogo street as continuation of Karla Moderakha street (Chernyishevskogo street will also be reconstructed);
– a passage going along facades of the buildings will be built between passages along Geroev Khasana street and Chernyishevskogo street.

We performed acoustic calculations on the examined territory for the future carefully taking into account all prospect changes in number of noise sources and screening objects basing on design plans for the new RQ construction.

Calculations were performed as per the same algorithm at heights from 1.5 meters to 75 meters within calculated rectangle boundaries on the examined territory with its sizes being 0.9 km * 0.9 km at 38 different heights, from 1.5 to 75 meters, according to the greatest number of floors planned for building within the RQ and bearing in mind that each floor is 3 meters high.

3. HYGIENIC ASSESSMENT OF ACOUSTIC CALCULATIONS RESULTS PERFORMED WITH GEOGRAPHIC INFORMATION SYSTEMS (GIS)

3.1. Acoustic calculation results analysis

Our primary analysis of construction design and plans revealed that the examined territory where the new RQ was to be located had various buildings and communal constructions only 1 floor high (Fig. 2a). The new planned RQ, including housing buildings, a school, and a trade and entertainment center, will be made of buildings with various number of floors, from 3 to 25 (Fig. 2b).

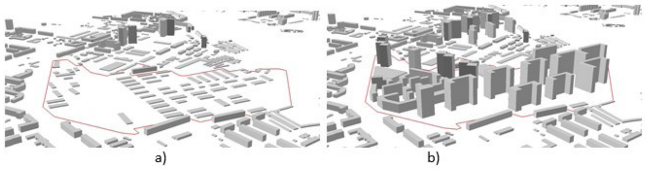

Fig. 2: The examined area and buildings on it (a – prior to RQ construction, b – after the RQ is constructed)

Acoustic calculations were performed basing on created database on mobile noise sources (motorways) at various heights (from 1.5 to 75 meters), the greatest one being determined as per the greatest number of floors planned for buildings within the RQ, namely 25.

Acoustic calculations for the existing situation (prior to RQ construction) on the examined territory revealed that noise levels at 1.5 meters (a height at which people usually hear any sound or a ground level) varied from 23.2 dBA (acoustically quiet zones) to 73.1 dBA (at a motorway) (Figure 3a). Noise levels varying from 30.9 to 57.7 dBA (up to 2.7 dBA higher than hygienic standard) were determined within boundaries where construction was planned and it practically corresponded to existing hygienic standards for day time.

Obtained data indicated that acoustically quiet zones occurred most frequently in yards due to sound insulation and screening provided by buildings and constructions located on the residential area perimeter.

To assess a range of changes in noise levels depending on a height, we analyzed results obtained via "layer-by-layer" acoustic calculations within boundaries of the area where construction was planned. Overall, we established that only insignificant deviations from hygienic standards (up to 3 dBA) were expected on the examined area where the new RQ was planned to be built. Calculated minimal equivalent noise levels grew steadily with height of screening buildings from 1.5 to 75 meters (with slight stabilization at 37-41 meters, 44.9 dBA, and 57-63 meters, 45.6 dBA). Maximum equivalent noise levels went down, starting from 1.5 meters, first of all, due to screening preventing noise from propagation, from 57.7 dBA (1.5 meters) to 55.1 dBA (at 75 meters), and they periodically stabilized at 19-27 meters (54 dBA), 47-53 meters (54.2 dBA), and 63-75 meters (55.1 dBA).

The second stage in pour research involved assessing probable changes in acoustic situation due to large housing construction (28 building altogether, including a TEC and a school). Changes in acoustic situation on the examined territory would be determined by new motorways (noise sources) and apartment blocks (screening objects). Geroev Khasana street, Chernyishevskogo street, and Chkalova street, together with three new streets (Vilgelma de Gennina street, Vasiliya Tatischeva street, and Karla Moderakha street) and 12 new passages were considered as primary traffic flows.

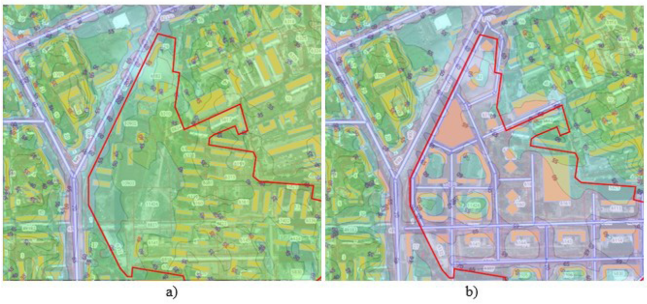

Fig. 3: Noise levels distribution at 1.5 meters (a – prior to RQ construction, b – after the RQ is constructed)

Acoustic calculation results performed for the future situation (taking into account completed RQ construction) allowed establishing that overall noise levels at 1.5 meters would vary from 30.1 dBA (acoustically quite zones) to 73.1 dBA (at a motorway) (Figure 3b). But at the same time, given high buildings located within "Arsenal" RQ, acoustic calculations revealed that expected noise levels would vary from 47.9 to 71.3 dBA (2.9 dBA higher than hygienic standard at night and up to 16.3 dBA higher than hygienic standard during a day).

We performed "layer-by-layer" analysis of acoustic calculation results taking into account the new RQ and revealed that changes in noise levels were quite specific at each height and depended, first of all, on incoming noise and the nearest screening objects.

Minimal equivalent noise level dropped dramatically at 3-7 meters (29.6 dBA) due to screening and then grew considerably starting from 9 meters (30.4 dBA) to the greatest height of 75 meters (46.1 dBA). Maximum equivalent noise levels went down starting from 1.5 meters, first of all, due to screening that prevented noise form propagation, from 73.1 dBA at 1.5 meters to 59.5 dBA at 75 meters.

We should note that both scenarios created for the examined territory that was close to the motorways showed that there were zones with acoustic discomfort and they influenced noise levels depending on changes in heights of buildings located close to the motorways.

Fig. 4 shows results of three-dimensional visualization showing noise levels at points located at various heights, both existing situation and future prospects (after the RQ is built).

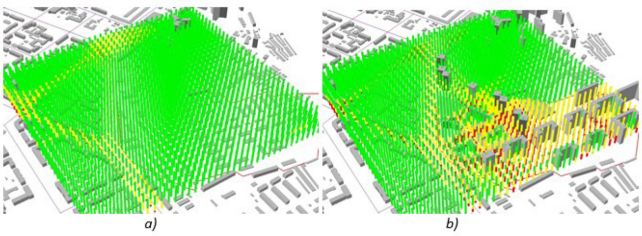

Fig. 4: Three-dimensional picture showing acoustic exposure (a – prior to RQ construction, b – after the RQ is constructed)

Modeling results allowed determining zones and heights where existing hygienic standards regarding noise levels were violated; it was done bearing in mind average daily noise exposure (as per data on average daily traffic intensity).

Results obtained via three-dimensional modeling give a comprehensive picture of typical noise propagation that occurs due to traffic flows within densely populated residential areas in a city. There is absolutely no guarantee that hygienic standards regarding noise will be met and sufficient acoustic comfort will be provided; given that, it seems obligatory to apply new constructive, planning, organizational, or other decisions made by municipal authorities.

The approaches described in the present work are the vital given the growing traffic intensity in large cities and megacities.

4. CONCLUSION

Studies that involve modeling calculations combined with databases on adverse exposure sources and geoinformation systems allow achieving the following:

- determining zones with elevated noise exposure on an examined territory for well-grounded decision-making;
- working out recommendations on functional zoning and spatial development of municipal territories, including general city planning schemes;
- developing subject layers that contain results obtained via ecological situation analysis for providing state authorities with relevant information and for integrating these layers into upper-layer GIS;
- substantiating programs for targeted help rendered to people living in zones which are unfavorable as per their sanitary-epidemiologic parameters;
- optimizing programs for social and hygienic monitoring over environmental factors;
- visualizing results obtained via social and hygienic monitoring activities for making them more available and understandable for general public.

Our three-dimensional model showing acoustic exposure at various heights starting form 1.5 meters and up to 75 meters allowed establishing certain regularities in changes in noise levels taking heights into account (heights from 27 to 33 meters, or 9-11 floors, were the most crucial due to multiple noise waves reflection). We took a new residential quarter being built at the moment on a territory with intense traffic flows as an example and managed to substantiate that it was necessary to include acoustic estimates, both for the existing and future situation, into project documentation when planning residential areas development and building city infrastructure as it would allow providing sanitary-epidemiologic well-being for city population.

Our research results indicate that it is necessary to perform permanent control over sanitary-epidemiologic well-being of the population and to develop mechanisms used to provide it; these activities are to be performed by municipal authorities. Besides, our data can be used as substantiation for developing and implementing environment protection activities aimed at reducing noise levels at the examined territory due to technical, architectural, planning, organizational, and other measures.

Our algorithm for calculating acoustic estimates using GIS gives an opportunity to expand areas of analysis and to increase quality of obtained results; it will help solve tasks related to complex sanitary-epidemiologic analysis both for Perm region as a whole and Perm city in particular and for other regions and territories as well. Taking noise factor into account is an integral component in planning housing construction if we are eager to provide favorable city environment.

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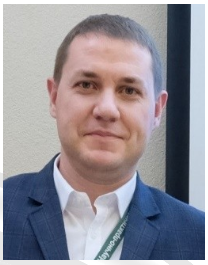

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