DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

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STUDYING A GEOGRAPHICAL ENVIRONMENT FOR ROAD DESIGN

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Statement of the problem. The state of theoretical studies in the field of engineering and landscape zoning is detailed.

Results. The analysis made it possible to outline the goals, objectives and the general methodology of research and modeling of organization and planning processes for the construction of departmental roads considering micro-landscapes, varying degrees of complexity of road construction, value of natural resources, species qualities of a road area as well as to optimize the design process of departmental highways.

Conclusions. The suggested comprehensive assessment of the natural and technogenic conditions for the construction of departmental highways is gaining economic, technical and environmental significance and can be employed as the basis for landscape design of departmental highways.

Keywords: road design, geographical environment, engineering and landscape zoning, landscape, road, integrated assessment.

Introduction. Viewing nature as a living, developing organism, a self-regulating system is an achievement of the past few decades. As this concept emerged, so did a new branch of science in geography, i.e., landscape science, which explores the structure, morphology, and dynamics of the development of the geographic environment. In this day and age, landscape science

is becoming a scientific foundation for a comprehensive study of natural conditions for the purposes of agriculture and forestry, urban planning, balneology, land reclamation and other types of economic activity as well as serves as a basis for design solutions.

The accomplishments of physicists and geographers in natural-historical zoning of Russia were a starting point for road-climatic zoning. Later on, some additions were introduced considering the climatic indicators of the previously identified road zones. The criteria for zoning in five road-climatic zones are based on the “balance of heat and moisture considering the general features of road construction” [8].

Road-climatic zoning has become the foundation for a comprehensive evaluation of the geographical environment for the design of subgrade and road pavements, which allows the design principles to be standardized.

Along with the positive aspects of a comprehensive study of natural conditions, the existing road-climatic zoning does not completely comply with the design requirements. It should be noted:

1. A vector, formal approach of designers to the evaluation of natural conditions and the application of standards for the design of subgrade and road pavements;
2. Lack of guidelines for improving the system of comprehensive evaluation of the geographic environment of smaller territorial units (subzones, regions, landscapes, etc.), thus ruling out the possibility of employing these data for tracing departmental highways;
3. Zoning is largely based on the analysis of climate and soil and subgrade, while such components of the geographic environment as topography and geological structure remain neglected. In the recent years, there has been a number of studies by domestic road scientists [3, 6, 8, 10, 12, 15, 17] where the need to clarify and detail the existing system of road-climatic zoning is identified.

1. Theoretical provisions and methods of road zoning are suggested in the studies by V. M. Sidenko, V. G. Kozlov, K. A. Yakovlev, etc. [8, 17]. So far, this has been the first attempt to theoretically substantiate the principles of regional evaluation of natural conditions. The authors argue that the key method for studying the geographic environment is road zoning, i.e., “a method of combining homogeneous territories by any criteria that have a major impact on the design, construction or operation of departmental highways” and they divide zoning into “physical” and “engineering” [4]. Physical zoning relies on the principle of allocating territories according to “geographic complexes”, engineering ones — according to road criteria.

The major geographic complexes are classed by the authors as climate, relief, geology, soils, ground and surface waters, vegetation whose role depends on the purposes of region-

alization. The characteristics of geocomplexes that impact the strength and durability of a departmental road or the construction process are referred to as road criteria.

For design purposes, V. M. Sidenko [18] suggests that the calculated moisture content or strength of soil foundations, the maximum amount of heaving, etc. is taken as a criterion. For construction purposes this is the timing of the start and end of road construction works, optimal in terms of climatic conditions, etc. zoning criterion for the operation of departmental highways — wind direction, “snowfall”, frequency of snow drifts and other characteristics.

The major theoretical provisions of road zoning rely on the following scheme:

1. The foundation of regionalization is landscape science, i.e., study of a landscape;
2. Differentiation of the geographic environment should be based on the patterns of zonal and azonal changes;
3. A zone, subzone, district, site is set forth as a taxonomic system of zoning.

The first two units are assigned to the highest rank, the subsequent ones to the lowest.

The zoning technique, according to V.M.Sidenko, is carried out in the following sequence:

1. The system of geocomplexes is substantiated, their impact is identified depending on the accepted road criterion;
2. The change of geocomplexes in time and space is considered and their calculated value is identified;
3. The regularity of the change in the road criterion is established depending on the change in geocomplexes, which allows for road zoning.

According to V. M. Sidenko, the major task of road zoning of the territory is the differentiation of micro-districts into districts. The theoretical provisions and the method of road zoning developed by the author [18] constituted the basis for zoning. The given detailed presentation in the study by V. M. Sidenko had two goals: to show the level of theoretical development of the issue of road zoning at the current stage and to make a number of critical remarks on the issue.

We believe that the major disadvantages of the work are the following:

1. The theoretical provisions of road zoning are developed merely as a scheme, there is no clarity in how the material is presented. E.g., the author argues that “the higher regions should be the foundation for general road zoning, natural for design, construction and operation”, and here he goes on to say that “there can be no single zoning, suburban for all cases”;
2. The terms and concepts used by the author in the work (e.g., “a geocomplex”) have not been sufficiently explained;
3. “Road criteria” are presented different for design, construction, operation, while in the design of departmental highways, they should be considered in combination;

4. Road zoning is not clearly defined. In our opinion, it would be more correct to define it as in the collective monograph by A. A. Kamusin, V. V. Nikitin, I. N. Zhuravlev, V. G. Kozlov, V. N. Logachev, I. I. Bukhtoyarov [7]. What sets this work apart is a clear statement of the problem, a methodology for identifying the quantitative characteristics of the components of the geographic environment, such as climate, ground hydrological and permafrost features. The zoning is based on factors influencing the stability of road structures: the type of soil in the seasonally thawing layer and its moisture content, the nature of the distribution of permafrost soils and their temperature, the thickness of the seasonal thawing layer. The studies made it possible to clarify the boundaries of the zone and divide it into road areas using which the principles of design and construction of the roadbed in 1 road-climatic zone were developed.

Studies on the road-climatic zoning of the foothills were performed by M. D. Krutsik, V. K. Kuryanov, E. V. Kondrashova, etc. [5, 8—9, 11, 13—14]. According to the characteristics of the climate, vegetation, and soils, the authors identified three road areas for which rational types of road pavements were identified, and the duration of the construction season was established. The work sets out to improve design and construction methods. In order to differentiate the territory, the authors utilized the method of overlaying maps of the same scale reflecting the spatial distribution of the major components of the geographic environment: climate, relief, soil. The issues of the methodology of road zoning are covered in [16, 21, 23]. According to their authors, zoning is “a set of practical techniques and methods for dividing a territory” in compliance with the tasks of examining natural characteristics. The following examples are proposed for designing non-rigid pavements:

1. The overlay method widely used by V. M. Sidenko, M. D. Krutsi, etc.;
2. Leading factor method;
3. The method of conjugate regional state of structural elements of road pavements.

The zoning relies on identifying natural factors that directly impact the choice of the type, design and strength indicators of road pavements. This data allows one to:

1. Identify the boundaries of the road and climatic zones for which the strength of the soil has a different value;
2. Establish the degree of provision of construction with road-building materials;
3. Determine Identify soil types;
4. Identify the characteristics of the area and the degree of moisture.

The objectivity of the division of districts into groups of complexity was tested by means of the method of mathematical statistics. The research results are of some interest for road construction planning and set out to improve survey work.

An assessment of natural conditions in the central part of the Russian Plain for the purposes of road construction is presented in the work by N. V. Isheeva [2, 17]. For the engineering evaluation, the “price increase factors” of the cost of 1 km of road construction were employed.

The studies by physicists-geographers are of indisputable interest and make a considerable contribution to the development of the theory and methodology of road zoning. However, in our opinion, such work should be performed in close contact with road engineers. This path is considered the most viable one by the physicists-geographers themselves [6, 19].

In overseas practice of road design, there is also a tendency towards an integrated accounting of physical and geographical conditions [6, 19].

The Interdepartmental Authority for Road Research of the USA presented the report “The Dependence of the Design of Highways on Local Physical and Geographical Conditions”. The report summarizes information about local road-building materials, the load-bearing capacity of soils and their changes under the influence of moisture based on the abyss resistance, the area of the United States is divided into 97 physical-geographical regions [19—22].

While designing the road network in Mexico [22], special application maps were developed for evaluating the road construction conditions reflecting the population density, the nature of the relief, the degree of economic use of the territory and development prospects, the density and configuration of the existing road network. Apart from comprehensive research, the study and mapping of the patterns of distribution of individual components of the geographic environment for road design purposes is being performed.

The issues of the methodology for evaluating the relief are covered in the study by N. A. Sitsenko [8]. An objective characteristic is presented in the form of graphical curves of the percentage of slopes. Graphs allow the slopes of the terrain to be determined and can be used in order to substantiate the geometrical characteristics and regionalization of territories based on relief conditions.

In Finland, studies have performed [22] into the effect of relief on the geometry of roads. The classification criteria for the regionalization of the territory were the complexity of construction.

2. Comprehensive study of the geographic environment for tracing highways. The issue of exploring natural conditions and human economic activity as factors central to the directions and location of the road route are of particular importance. The more complex the natural and man-made situation in the survey area is, the more information a road engineer must process for solving road tracing problems.

Road routing is the most relevant and daunting stage of road design. The engineer must have sufficient knowledge of the dynamics of a car as well as of natural conditions and the

capacity to identify the most successful spatial line, i.e., a road route that complies with communication, economic, ergonomic and environmental requirements. It is in the process of routing that the basic preconditions for landscape design of departmental highways are laid out. The problem of road design is being tackled both in Russia and overseas [1, 8, 17, 23] from these exact positions.

However, in spite of the relevance of the problem of examining natural and man-made conditions for tracing roads, it should be noted that little attention has been paid to it in road design. S. A. Treskinskiy, who proposed a methodology for a comprehensive assessment of natural conditions when choosing the direction of the road route [8], can well be considered the founder of a comprehensive study of the geographic environment for tracing departmental highways. He developed an evaluation system that is performed in three stages:

- at the first stage (the stage of selecting the general direction of the route), using small-scale maps 1 : 2 500 000 — 1 : 500 000, convenient transport landscapes are outlined, i.e., passes, valleys, flat spurs and slopes;

- the second stage involves identification of possible options in the strip of the selected general direction. It is carried out by assessing natural conditions by means of the linear zoning method using maps of a scale of 1 : 100 000 — 1 : 25 000. Linear zoning is actually landscape zoning;

- the third stage involves the alignment of the route and the establishment of its geometric parameters. The study of the natural situation at this stage is reduced to addressing the problem of the optimal combination of road elements with the surrounding area, its relief and vegetation.

At the first stage, the zoning technique for tracing roads includes the design of schematic maps of the study of territories in the area of the suggested construction showing meteorological stations, areas investigated by third parties, climatic characteristics, relief, soils, surface runoff, geology, tectonics, vegetation. For these purposes, literary stock materials, maps for various purposes, information obtained from unmanned aerial vehicles are utilized.

At the second stage, using the previously collected material, the most significant factors are discussed and plotted on a large-scale schematic map. The key role is played by the structure and sculpture of the mountains.

However, road tracing is closely related to the overall set of natural conditions. Therefore the art of selecting the optimal location of the road route depends on the explorer's capacity to identify the key aspects of each process and evaluate its positives and negatives. It is from this standpoint that S. A. Treskinskiy develops the method of road-landscape zoning: "Each visible sign is decoded as a reflection of either an evolving or a dying process" [8]. According to the

author, regionalization should rely on the genetic principle, i.e., the study of the historical development of the geographical environment as a whole throughout the whole area.

While constantly working on improving the system for examining the natural situation for tracing roads, S. A. Treskinskiy [8] suggests that road conditions are evaluated based on “probabilistic difficulties” using a six- or eight-digit code system. His system of codes enables one to evaluate the degree of influence on the engineering structure of such components of the geographical environment as climate, relief, geological structure, hydrology, and human economic activity. This method does not cause difficulties in practice and, most importantly, rules out the possibility of underestimating natural phenomena. However, the system set forth by S. A. Treskinskiy allows one only to obtain a qualitative characteristic of the road construction conditions.

The work by L. B. Zotova [17] is of particular interest where a geobotanical method for evaluating soil conditions was developed for tracing roads in 1 road-climatic zone. The method relies on the use of plants and their communities as indicators characterizing the permafrost soil conditions of the area. In the process of engineering-geological surveys, vegetation is described by areas, and by means of comparing these data with indicator tables, characteristic permafrost-soil conditions in the survey area are established.

In the lacustrine-bog landscape, 5 microlandscapes are identified: a lake water area, a moss bog, a lake-moss bog, a dry island, a watershed area. The foundation for drawing up a relief-landscape scheme is the engineering-geological interpretation of aerial photography materials. Constructed based on these data on a scale of 1 : 25 000, the plan-scheme of microlandscapes allows one to objectively place and design a linear structure with minimal costs.

Considerable progress in the field of routing of departmental highways has been made in the recent years and is due to the introduction of modern information technologies into road design. This enabled one to move on to searching for new principles for evaluating the road route, development of mathematical models and tracing methods [3, 8].

Modern methods for tracing departmental highways can be classed as:

1. Automated systems for processing a complex of computational work required in the design of departmental highways (they do not provide optimal solutions);
2. Methods for the optimal design of the project line in a longitudinal profile or in plan and profile together; optimization is performed according to the minimum amount of work as well as the distribution of earth masses and other criteria.

The choice of a viable option is associated with the need for a considerable amount of information, which calls for a preliminary selection of a strip of terrain, within which the optimization of road design is performed;

3. The method of choosing a “corridor” for tracing, which involves ensuring the compliance with economic, social, aesthetic and environmental requirements by considering and analyzing the topography and identifying transport landscapes, the value of areas, the presence of settlements, historical monuments, vegetation, specific characteristics of the area, unfavorable physical and geological processes and phenomena. Based on these data, a routing “corridor” is mapped out where competing options are laid out, and an acceptable position of the road route is identified by means of the optimal design method.

V. F. Babkov suggests that the method of analyzing the plans of the area of the road to be used to identify the “corridor” of tracing [3] is employed by means of the method of imposing plans on the topographic map where the areas that are unfavorable due to natural and technogenic conditions, places of undesirable disturbance of the ecological balance, valuable natural resources, etc. are marked.

The need to analyze a significant amount of information causes overseas design organizations to design specialized “environmental groups”. The main task of the groups is to substantiate the direction of the road considering economic, physical-geographical, aesthetic factors [8].

Bringing together specialists from various fields of knowledge in selecting of a viable direction of the route is somewhat challenging, as, first and foremost, the cost of developing project documentation rises. Lately, there has been a tendency to design different kinds of mathematical models of the geographic environment. In particular, W. L. Smith [21] sets forth a probabilistic model for evaluating the environment, land use, population density and other factors using “supply and survey” system. The tracing method using the “cost of lines and zones” was suggested by G. C. Athanasgolis and V. Galogero [23].

The modern system of views on the introduction of a road into the geographic environment should be underpinned by the urge to minimize the change in the structure and dynamics of territorial complexes, preserve the external appearance of the landscape as well as to curb unfavorable natural man-made processes.

An example of landscape-ecological zoning is a work by American specialists I. A. Kuhn and I. L. Coggin who developed a system for analyzing natural conditions and human economic activity using special maps [23]. Evaluation of the geographic environment in terms of sustainable design and environmental protection is performed in three stages.

On a small-scale map 1 : 2 500 000, specific natural elements are indicated, according to these data, a “corridor” for tracing is identified. Direct choice of the location of the road alignment is performed using maps of scale 1 : 62 500, which are considered most convenient. The development of individual sections is performed using maps of a scale of 1 : 24 000 where it is

convenient to solve issues of land acquisition, future changes in the road situation, these maps are used to lay out options for the route with specialists and the public.

The set of initial data in order to identify the rational route option is processed using information technology. The authors of [23] set forth two methods of data processing. The first one is based on evaluating the natural situation by means of a grid of rectangular cells where elements of the road situation are introduced. The second method involves evaluating the road situation by processing a set of initial data entered in advance into an information system that produces results at various polygons.

Traffic information enables one to choose a viable version of the road route and identify its impact on the environment.

3. The current state of studies of the geographic environment for road design. Natural conditions and human economic activity have the most direct impact on road construction production (design, construction and operation of departmental highways), which calls for a profound and comprehensive study. The analysis of the current state of studies of the geographical environment for road design allows one to conclude the following:

1. The study of the geographical environment is performed in two major directions:
 - a) a comprehensive study of natural conditions;
 - b) a study of different characteristics of the components of the geographic environment.
2. A comprehensive study of natural conditions is performed by means of road zoning, i.e., a system for collecting and processing information about natural conditions, according to the results of which natural (modified by economic activity) complexes of various ranks, i.e., road zones, subzones, districts, landscapes, microlandscapes are evaluated, identified and mapped.
3. The study of individual characteristics of the components of the geographic environment is commonly performed by means of statistical processing of data from direct measurements, which are used to design schematic maps of the distribution of the calculated characteristics of the components of the geographic environment in the study area.
4. In the modern system of a comprehensive study of the geographic environment, three types of regionalization can be distinguished: road-climatic, road, road-landscape.

Road-climatic zoning allowed one to establish the general patterns of distribution of climatic conditions in Russia and to develop standards and technical conditions for the design of subgrade and road pavements using it.

Road zoning is in the stage of intensive development, the key research is being carried out into the patterns of change in the calculated characteristics of the subgrade soils, which are formed under the influence of climate, the relief of surface and ground waters.

The foundation of road zoning is the theory and practice of physical and geographical zoning, which “involves a reasonable identification of physical and geographical regions and their detailed characteristics which would show the existing profound connections between individual components, complexes, processes and phenomena, the history of the development and formation of complexes, given an in-depth analysis of natural resources, both qualitative and quantitative one” [17].

The road zoning technique includes:

1. Collection and processing of information about natural and man-made conditions of road construction;
2. Analysis of the results;
3. Evaluation;
4. Mapping.

A comprehensive study of local territories (landscapes and microlandscapes) and their evaluation from the point of view of the complexity of road construction, disruption of the natural balance, species qualities is what we call road-landscape zoning. The study of local territories for road tracing and landscape design of departmental highways is the most challenging and time-consuming task, which, despite being obviously relevant, has not been sufficiently addressed. The complexity and diversity of identifying the criteria for zoning, which have not yet been developed in a quantitative form, provide a solid foundation for doing extensive research into road-landscape zoning (Fig.).

Fig. Scheme showing the sequence of road zoning

Conclusions

1. The analysis of studies of the geographic environment for road design leads us to assume that the issue of evaluating natural conditions and human economic activity in local areas, i.e., landscapes and microlandscapes, is currently the least developed one. However, this type of evaluation is the starting point for developing technically correct and economically feasible design solutions regarding the choice of the location of the road route, identification of construction costs, development of measures for protecting and rationally using resources, i.e. all those issues that are intended to be solved landscape design. Therefore a comprehensive evaluation of the natural and human-made conditions for the construction of departmental highways takes on the economic, technical and environmental importance and is the foundation for landscape design of departmental highways.
2. The analysis of the state of theoretical research in engineering and landscape zoning of territories allowed us to outline the goals, objectives and general methodology of research and modeling of the processes of organizing and planning the construction of departmental highways considering microlandscapes and varying degrees of complexity of road construction, value of natural resources, and the specific qualities of the area of the road, as well as to optimize the design process of departmental highways.
3. The drawbacks in the road construction of departmental highways can be by and large addressed by means of implementing the results of scientific research in production aimed at improving the methodological foundations of tracing departmental highways via geo-information support of engineering landscape design.
4. According to the authors, the system of road-landscape zoning should have four types of evaluation of local territories: engineering-landscape evaluation, which characterizes the degree of influence of the components of the geographic environment on the complexity of road construction; landscape-ecological reflecting the influence of the components of the geographic environment on the complexity of road construction; landscape-ecological reflecting the influence of departmental highways on the geographic environment; architectural-landscape reflecting the species qualities of territories; a comprehensive evaluation characterizing the interaction of the “geographic environment — engineering structure” system.
5. All of the above serves as a testimony of the relevance of the problem for improving the efficiency of construction of departmental highways.

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