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# HIGHWAYS DESIGN TAKING INTO ACCOUNT CLIMATIC FEATURES IN THE ROUTE AREA

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**Statement of the problem.** In order to obtain optimal design solutions that meet the conditions of safety traffic in difficult weather conditions, it is necessary to compare the options of highways according to the snow tolerance conditions. Such calculations should become an integral part of the CAD-AD computer-aided design system.
**Results.** A systematic approach to solving the problem is set forth, a list of information necessary for calculations is identified. The results analysis of studies on the snow-bearing capacity of roads conducted in Russia and abroad is carried out. Calculation schemes and models are suggested to evaluate options for the longitudinal profile and the roadbed for the snow-bearing capacity. Solutions for evaluating variants of the route plan using maps with calculated parameters of snowstorms are proposed.
**Conclusions.** The implementation of the proposed calculation methodology will make it possible at the design stage to evaluate the options of the highway according to the conditions of the snow-bearing capacity.

**Keywords:** highways, design, route plan, roadbed, snow bearing, information modeling.

**Introduction.** Designing a modern, comfortable and safe transport infrastructure is one of the urgent national tasks facing Russia's road sector[1]. 12 strategic directions of development for the period up to 2024 are part of the national project "Safe and High-Quality Highways" which provides a number of measures for improving traffic safety. In order to implement them, the number of highways complying with the regulatory requirements must be increased. Special attention is paid to the solution of such problems at the design stage where the major transport and operational indicators are specified for both newly designed highways and those where reconstruction or major repairs are planned.



[1] Section 8 of the Decree of the President of the Russian Federation of May 7, 2018 "On The National Goals and Strategic Objectives of the Development of the Russian Federation for the Period up to 2024".

The most dangerous for road users is the winter period, when traffic safety is greatly affected by snow drifts and winter slipperiness in the form of snow roll.

As information modeling technologies are being developed in the road industry, there are new opportunities for addressing the tasks specified in the national project. The foundation of such technologies is the development and use of an information model of a highway built at the design stage and supplemented with information at the maintenance stage[1]. At the recently held annual conference on computer-aided design of roads BIM GENERATION 2021, the relevance of addresing the problem of evaluating design solutions for snow drift and the lack of opportunities for doing it in computer-aided design systems (CAD-AD) was brought up.

The experience of scientific research into snow-covered roads available at the Department of Road and Bridge Design of the Voronezh State Technical University allows us to set forth the ways of addressing the problem [3—5, 10, 12—15, 17].

The objective of the study is to describe a systematic approach, design schemes and models for addressing the problem of evaluating options for design solutions for snow drift. The object of the study is road projects in regions with severe winter conditions.

**1. A systematic approach to solving the problem.** Both in the design and operation of highway, the tasks of considering the influence of climatic conditions on the safety of vehicles should be solved using a systematic approach set forth by A.P. Vasiliev [2, 18]. The block diagram of the DCRE system (driver-car-road-environment) and its subsystems for the problem are shown in Fig. 1. The influence of climatic conditions in the evaluation of design solutions can be accounted for within the framework of the analysis of the subsystem "Road and Environment" [14].

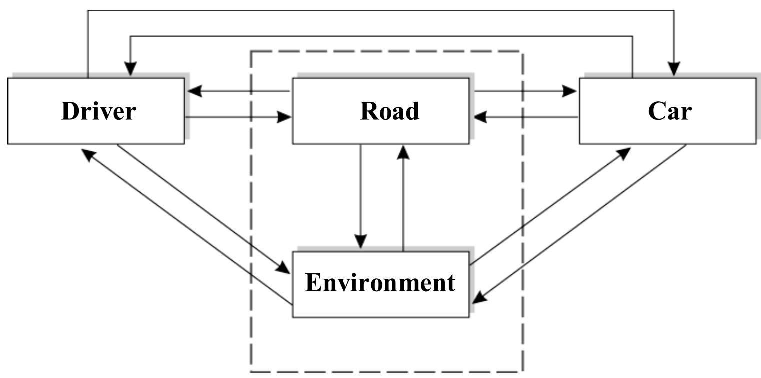


**Fig. 1.** Structural diagram of the DCRE complex and subsystem, allocated for the task of designing roads considering the climatic features

[1] SP (СП) 333.1325800-2020. Information modeling in construction. Rules for the formation of an information model of objects at various stages of the life cycle.

The external environment in the DCRE system is characterized by a set of weather and climate factors. According to Prof. A. P. Vasiliev [18], while dealing with road problems, it is more correct to consider the entire natural environment, including relief and vegetation. It should be noted that considering the features of the design stage, a situation, the geological structure of the area can be added.

Providing organizations involved in the design of roads with meteorological information resources is one of the tasks of the Federal Service for Hydrometeorology and Environmental Monitoring (Roshydromet). Roshydromet information is subdivided into general-purpose information and specialized information which is supplied by a consumer's request at their own expense and reflects in more detail the meteorological parameters necessary at various stages of the life cycle of a facility. The classification of specialized meteorological information used at various stages of the life cycle of the road and the list of tasks that are solved using it are shown in Fig. 2 [11].

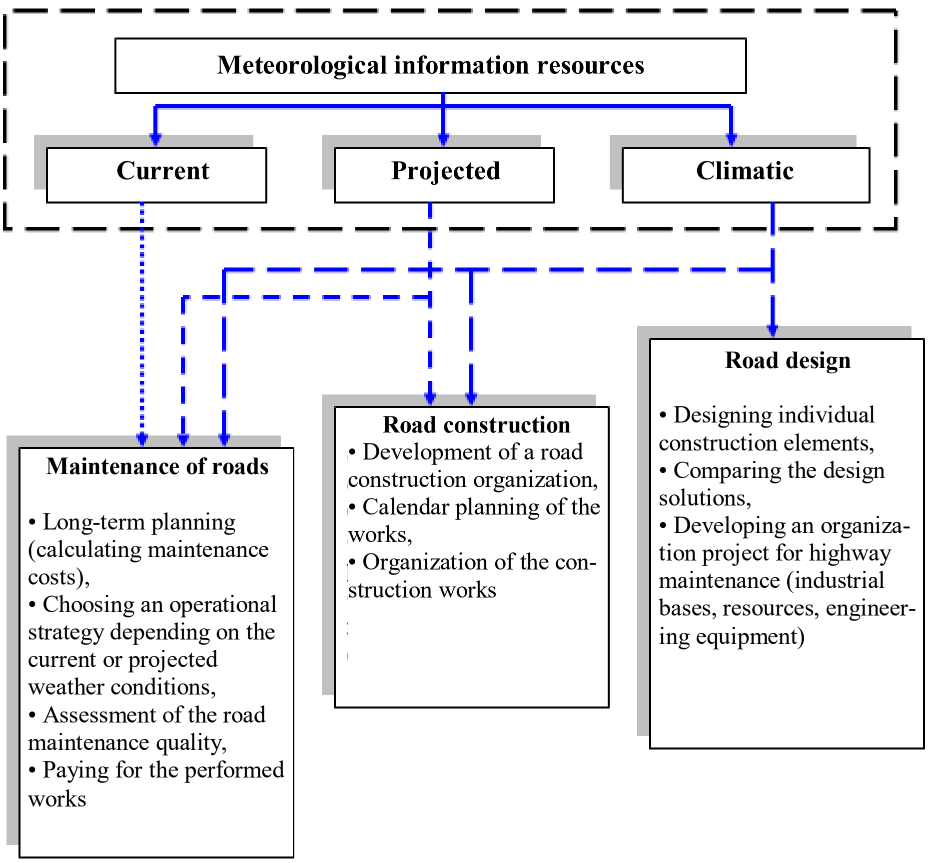


**Fig. 2**. Information resources of Roshydromet and their use at various stages of the life cycle of roads

While addressing the problem of designing and comparing route options, considering its snow resistance, the environmental factors are of a stochastic (random) nature and can be described by means of the probability distribution laws. The archive of meteorological information about snowstorms over a long observation period (15—20 years) is used as the initial data for calculations [3, 25].

While comparing options for design solutions and developing design documentation, it should be taken into account that for most regions of Russia, one of the most challenging and responsible road organizations in the work is the winter period. Besides the major expenses for snow fighting and combating slippery roads, the state suffers significant losses when the capacity of roads drops due to a decrease in the speed of vehicles or their complete stop on sections of roads heavily covered with snow. Winter maintenance issues must be tackled at the stage of designing or reconstructing roads. This being the case, the designed options for the route should be assessed according to the conditions of snow resistance. At the design stage, issues of engineering arrangement should also be considered, i.e., optimal snow protection schemes for various sections of roads, and calculation of resources for snow removal and protection for staying consistent the required maintenance level[2].

Until now, at the design stage, winter maintenance issues have not been resolved to such a degree, which is accounted for by the lack of appropriate calculation methods, information databases with the climatic conditions necessary for roads characterizing the winter period in various regions of the country as well as software enabling all the necessary calculations in CAD-AD.

Due to its complexity and multifactorial nature the problem of considering winter conditions at the design stage can be addressed step by step as part of the analysis of the "Environment — Road" (E-R) subsystem based on the general approaches of the theory of complex systems modeling. The law of operation of a complex E-R system can be represented as a generalized operator $F_s$ which converts a set of internal independent parameters of the system (climatic and road factors) into external, dependent ones (the condition of the pavement on a snow-covered area in winter) [14, 16]:

$$Y(t) = F_S(V, h, t), \tag{1}$$

where $Y(t)$ is a vector whose components are all possible states of the road surface in winter and their duration; $F_s$ is the law of the system functioning; $V$ is a vector of climatic factors affecting a roadway surfacing; $h$ is a vector of road factors; $t$ is the time.

It is necessary to design the road (components of the vector $h$) in such a way considering climatic conditions (vector $V$), so that the time the pavement is in an unfavorable condition

[2] GOST (ГОСТ) 33181-2014. Public Highways. Maintenance Level Requirements.

(snowy, drifts) is minimal. The model is a theoretical basis for addressing the problems of considering winter conditions in road design.

**2. Information needed to evaluate design solutions.** While addressing the issues related to the snow maintenace of roads, it is necessary to consider various factors - both calculated climatic and road ones. The major climatic factors are the estimated volume of snow in the winter $W_{пр.}$, the volume of snow in the calculated blizzard $W_{пр,\ расч}$, the annual duration of the blizzard period $T_з$, the duration of the calculated blizzard $T_{расч}$, the intensity of the blizzard $J$, the estimated volume of snow deposits at the end of the winter period $Q_{отл}$ [3, 25].

In order to compile an information database with the estimated parameters of blizzard activity necessary to address issues of snow maintenance of roads, “Method for Identifying the Estimated Volumes of Snow and Basic Climatic Parameters” has been developed for the conditions of a flat open area, an unlimited snow-gathering basin, if there is a sufficient amount of snow material for the implementation of the load-carrying capacity of a wind flow. In order to identify the amount of snow brought to a particular section of the road, corrections are made for the length of the blizzard acceleration, the presence of a microrelief and vegetation in the snow collection basin as well as the coefficient of snow loss to evaporation and melting during thaws in the periods in between blizzards [3]. This technique is implemented in the current regulatory documents.

Among the road factors influencing the snow conditions, the major ones are for the route plan — the direction (points) of individual sections, for the longitudinal profile — working marks and the transverse profile of the subgrade. These parameters are the most studied ones. Undoubtedly, the important factors are the terrain in the area of the route and the roadside situation, but they are not yet represented in the road methods and calculation models[3].

The amount of snow that can be deposited on the road depends on that of snow brought to the right and left of the road and on the geometric elements of the subgrade. The sections of roads passing along the upper third of the leeward slopes of the relief, sections at zero marks, low embankments and excavations are known to be the most vulnerable ones [18].

**3. Possibilities of using mathematical modeling to consider the climatic features of the area where the highway passes.** In order to assess the impact of snow and wind flow on the subgrade of the road, various studies were performed. Abroad [20—24] and domestically [1, 8, 9] there are results of scientific research on snow drift obtained as a result of physical modeling in special wind tunnels and specifically designed setups. Some models were ob-

[3] IRDM (ОДМ) 218.5.001-2008. Guidelines for the protection and cleaning of roads from snow.

tained as a result of special field observations in winter on snow-covered areas [19, 23, 26]. Modern programs for modeling hydrodynamic processes have also been employed to investigate the dynamics of snow accumulation near snow-retaining barriers [12, 20]. Analysis of the research results led to the conclusion that all of them are more suitable for the stage of maintenance and addrssing the problems of choosing snow protection tools.

The requirements for snow resistance to the designed roads are set out in the current regulatory documents[4]. Particular attention is paid to the assessment of the snow resistance of low embankments and cuts.

Here are formulas for calculating the amount of snow deposited on various types of transverse subgrade profile. They were obtained as a result of research performed by the authors over a few years.

The deposition of snow on the subgrade of embankments occurs due to a decrease in the speed of the snow-wind flow when it passes over a towering obstacle. The calculation scheme for determining snow deposits on a low embankment is shown in Fig. 3. The calculation was performed at characteristic calculated points of the diameter: I — windward cell; II — windward curb; III — windward edge; IV — the axis of the road; V — leeward edge; VI — lee edge; VII, leeward cell [5].

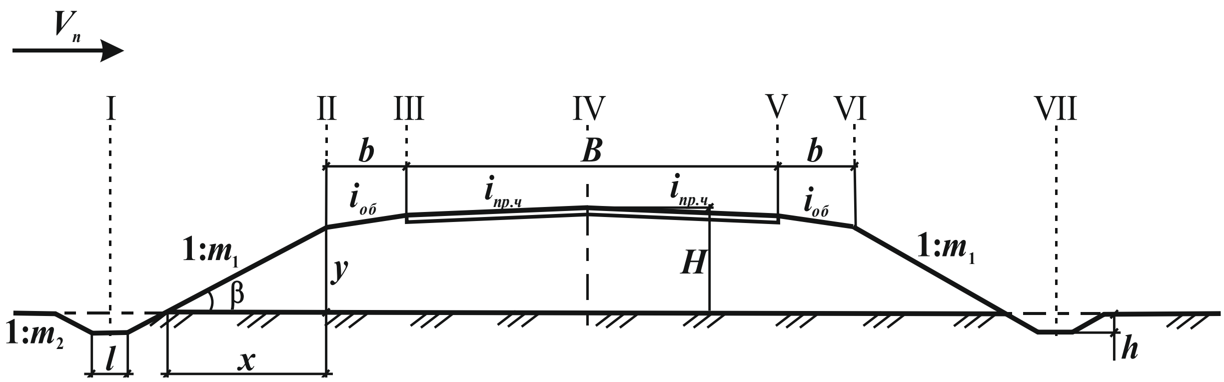


**Fig. 3.** Calculation scheme for assessing the snow cover of the embankments

Formulas for identifying the amount of snow deposited from the snow-wind flow on the subgrade of low embankments are given in Table.

According to the nature of the aerodynamics around the snow-wind flow, there are unopened and open holes. Unopened ones are characterized by the presence of a vertical vortex zone, and the open ones are circled around by the snow-wind flow without its formation [4, 6, 18].

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[4] SP (СП) 33.13330.2021. Automobile roads.

Table

Formulas for identifying the amount of snow deposited on the subgrade of the embankments

| Section number | Formula for identifying | | | |
|---|---|---|---|---|
| | The distance from the point of rising flows to the design section | altitude position of the design section | amount of snow deposits in the design section | Amount of the further snow deposits |
| II | $x = m_1 \cdot y$ | $y = H - \left(\frac{B}{2} \cdot i_{пр.ч} + b \cdot i_{об}\right)$ | $Q^{II}_{отл} = W_{пр1} \cdot П$ | $W_{пр2} = W_{пр1} - Q^{II}_{отл}$ |
| III | $x = b$ | $y = b \cdot i_{об}$ | $Q^{III}_{отл} = W_{пр2} \cdot П$ | $W_{пр3} = W_{пр2} - Q^{III}_{отл}$ |
| IV | $x = \frac{B}{2}$ | $y = \frac{B}{2} \cdot i_{пр.ч}$ | $Q^{IV}_{отл} = W_{пр3} \cdot П$ | $W_{пр4} = W_{пр3} - Q^{IV}_{отл}$ |
| V | $x = \frac{B}{2}$ | $y = -\frac{B}{2} \cdot i_{пр.ч}$ | $Q^{V}_{отл} = W_{пр4} \cdot П$ | $W_{пр5} = W_{пр4} - Q^{V}_{отл}$ |
| VI | $x = b$ | $y = -b \cdot i_{об}$ | $Q^{VI}_{отл} = W_{пр5} \cdot П$ | $W_{пр6} = W_{пр5} - Q^{VI}_{отл}$ |

According to A. K. Dyunin, an irrotational flow around open holes is possible with slopes less than 1 : 6 [7]. The results of experiments performed on models of deep holes in a wind tunnel, as well as field studies, show that the snow collection zone of unopened recesses can be divided into two parts — upper and lower, which is schematically shown in Fig. 4 [15, 26]. Similar results were obtained by the authors while modeling the processes of snow deposition on highways in the *FlowVision* software [12].

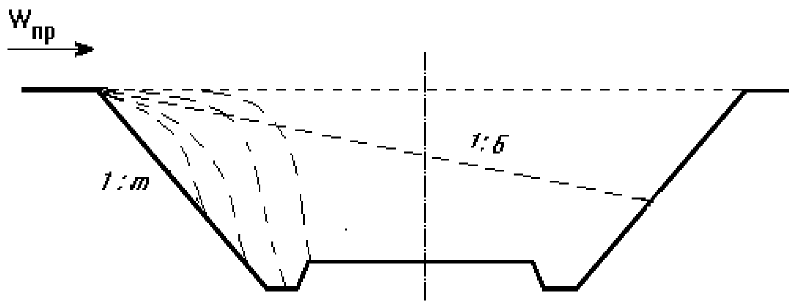


**Fig. 4.** Scheme of snow collection zones of unexplored excavations

In the upper zone, bounded by a line with a slope of 1 : 6, there is an irrotational movement of the snow-wind flow, but at a speed lower than the field one. Therefore the filling of this excavation zone with snow occurs slowly due to the loss of part of the snow from the snow-wind flow corresponding to the degree of decrease in the flow speed with snow deposited in a thin even layer.

In the lower zone, a vertical vortex is formed with a reverse movement of the snow-wind flow whose speed in the center of the vortex drops to 0 m/s. This causes complete precipitation of snow from the flow and its deposition in the zone of the vertical vortex. An intensive growth of snow deposits is observed and with a sufficient volume of snow, the entire eddy (lower) zone of the excavation is quickly filled [10]. The amount of snow deposited in unopened excavations, depending on the amount of snowfall and the geometric elements of the subgrade, can be identified with a sufficient accuracy for practical calculations using the method below.

A hole where all the snow brought to the road can fit in the deposits on the slope of the holes $Q_{отк}$ and the ditch $Q_{кюв}$ is considered not covered:

$$W_{пр} < Q_{отк} + Q_{кюв} = Q_{отк,кюв} . \quad (2)$$

The maximum amount of snow that can be deposited in this case on the lee slope and in the ditch can be identified by means of geometric calculations using a simplified diagram shown in Fig. 5. Numerous field observations of snow deposits enable us to conclude that the snow on the lee slope of the excavation has a slope of about 1 : 0.5 (line *BC*). Thus the amount of snow that can fit on the slopes and in the ditch is defined as

$$Q_{отк,кюв} = Q_{ABCEF} = S_{ABCEF} \cdot L , \quad (3)$$

where $S_{ABCEF}$ is the cross-sectional area of snow deposits, m$^2$; $L$ is the width of the strip of snow deposits for which the calculation is performed $L$ = 1 m.

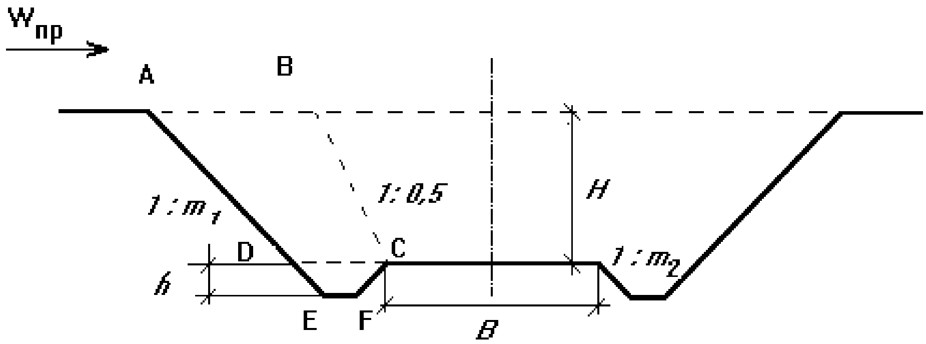


**Fig. 5.** Scheme for calculating the snow capacity of the lee slope and excavation ditch

As

$$S_{ABCEF} = S_{ABCEF} + S_{CEFD} , \quad (4)$$

the cross-sectional area can be identified based on the geometric characteristics of the slopes of the excavation $m_1$ and subgrade $m_2$, the excavation depth $H$ and the ditch depth $h$.

$$S_{ABCDEF} = 0,5\,[H \cdot (m_1 - 0.5) + 2h \cdot (m_1 + m_2) + 0.4] \cdot H + 0.5[h^2 (m_1 + m_2) + 0.8h]. \quad (5)$$

Considering the known volume of snow brought to the left and right to the road and the geometric characteristics of the right and left slopes of the excavation, the volume of snow deposits on the subgrade and roadsides to be removed is equal to

$$Q_{отл} = W_{пр.л} + W_{пр.пр} - \left(Q_{отл,кюв.л} + Q_{отк,кюв.пр}\right). \quad (6)$$

The average height of snow deposits on the road is

$$h_{cp} = Q_{отл} / B \,, \tag{7}$$

where $B$ is the subgrade width, m.

In order to automate the calculations, a software was designed that enables one to determine the amount of snow that can be deposited on the projected section of the road with a known estimated volume of snow and the geometric elements of the subgrade making it possible to assess the snow content at the design stage.

Hence the methods have been developed for quantitative assessment at the design stage of snow deposits on the subgrade of highways. Solutions have been obtained making it possible to compare options for design solutions, as the quantitative values of snow volumes enable us to proceed to cost estimates of the amount of snow removal work.

Performing such calculations makes it possible to evaluate only the options for designing a longitudinal profile and subgrade. In order to implement the models, the parameters such as the amount of snow brought to the road must be obtained.

This task is quite time-consuming and involves processing of a big amount of meteorological information. If it is solved, it will be possible to evaluate options for the route of the highway, change the direction of snow-covered areas depending on the volume of snow.

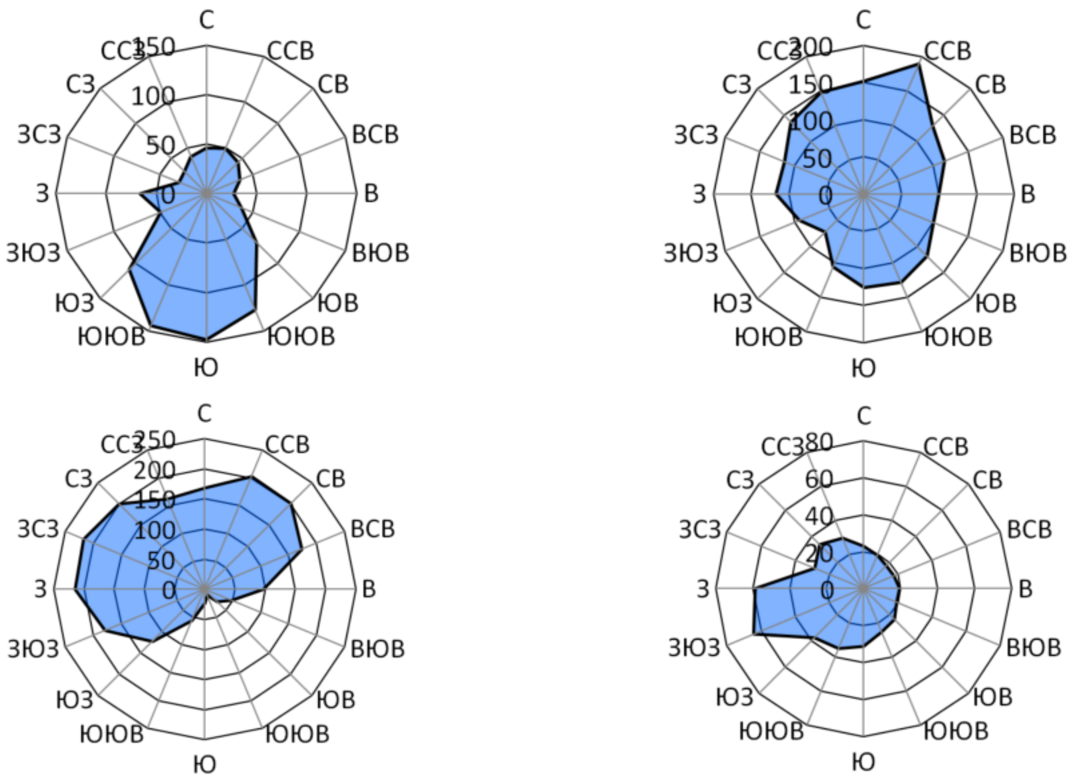


**Fig. 6.** Distribution of the total volumes of snowfall by points

According to the results of the study of the parameters of blizzard activity in the territory of the Central Federal District, the total volumes of snow drift differ considerably both in points (directions) and in numerical value. Examples of distribution of snowfall volumes for four meteorological stations are shown in Fig. 6. A section of the road will be covered with more snow if the direction with the maximum amount of snow is perpendicular to that of the road. If these directions coincide, snow will be carried by the wind along the road and not deposited on the slopes and in ditches.

At the present stage of digitalization of the road sector, the priority direction is the introduction of information modeling technologies. The development of such technologies for highways is at its early stage. The most solid solutions were obtained at the stages of surveys and design of transport facilities using CAD-AD. The resulting digital information model of the road is appropriate for use at subsequent stages of the life cycle, i.e., during construction and operation.

The foundation for the design of roads using information modeling technologies is a single digital sub-base in the form of digital models of the relief, situation, and geological structure of the area. It designs a digital model of the road during the design process.

Due to the lack of complete information on blizzards suitable for road design in climate reference books, it becomes essential to calculate the parameters of blizzard activity for road sections of various directions. The collection and processing of information for such calculations involves big financial, labor and time costs and cannot be performed for each road separately or for a specific projected section of the road, i.e., for a separate project.

The experience of designing snow protection measures for road maintenance projects has shown that the viable solution to the problem is developing a set of special maps, as information about the parameters of snowstorm activity is spatially distributed data. These maps can be used at the design and maintenance stages of roads [17].

The results of the research on the parameters of blizzard activity presented in this article can pave he way for the development of a separate subsystem for evaluating options for design solutions according to the criteria for snow drift, which will become an essential part of CAD-AD.

**Conclusions**

1. For the first time, a systematic approach to addressing the problem of evaluating the design solutions of highways based on snow conditions has been set forth. Information resources describing the design object and the external environment have been substantiated.

2. In order to assess the snow penetration of the transverse profiles of the subgrade, design

schemes and formulas for low embankments and cuts are set forth making it possible to compare the options for the designed longitudinal profile and transverse profiles of the subgrade.

3. In order to evaluate options for the route plan according to snow conditions, it has been for the first time set forth to make use of maps with calculated parameters of snowstorm activit allowing them to be utilized on par with digital models of the relief and geological structure of the area as a basis for designing in CAD-AD.

4. For the first time, the mathematical models and cartographic materials set forth in the complex fit logically into the concept of information modeling of roads and are appropriate for use at several stages of the life cycle of a road, both in design and maintenance.

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