Monitoring of changes in the thermal regime in the road structure

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Abstract. Freezing of wet dispersed soils is accompanied by a number of physical, physicochemical and physicomechanical phenomena and processes. In soils, when water freezes, the properties of the soils themselves change abruptly and abruptly, and the volume of frozen soil increases significantly, and not evenly. It was revealed that during freezing conditions can arise under which an increase in soil volume due to moisture migration to the freezing front and its freezing can reach tens of percent. This process is usually called frost heaving of soils. This phenomenon refers to physical and mechanical processes, as a result of which, under the influence of thermodynamic changes, the freezing soil acquires a stress-strain state. To combat frost heaving, it is necessary to study the patterns of changes in the water-thermal regime of road structures. The article presents various methods for assessing the water-thermal regime of road structures. The developed system of temperature monitoring of the road structure to a depth of up to 3 m and some measurement results are described, which make it possible to assess the temperature change at different depths from the road surface.

1. Introduction
The road is a common engineering complex, all the elements in it work as a whole in close interconnection. The reliable foundation of the pavement is the subgrade, which ensures its durability and strength, regardless of climatic, soil and a number of other factors. A subgrade is being erected on a soil layer, which changes its properties at different times of the year. Changes can occur due to the influence of natural factors such as air temperature and soil moisture. Consequently, the service life of a road structure depends on the condition of the soil located at the base of the road, its type and moisture content. In the warm period of the year, the seasonally frozen layer gradually completely thaws out and this state with a positive average annual temperature of the outside air is typical for approximately 50% of the territory of Russia. An analysis of the work of road pavements in areas with seasonal freezing shows that during these periods the greatest destruction and deformation occur in the subgrade and the structure of the pavement, which are the main problem of the poor quality of highways.

When solving the problems of increasing the pace of road construction and improving the operational reliability of highways, a promising area of activity is the integrated design of the route and roadbed structures based on the use of an integrated spatial relief model, elements of geology and
hydrogeology of the area. This is possible when conducting field research at stationary observation points in territories with seasonally freezing soils, with the development of regional (local) recommendations for the design and operation of highways.

2. Methods of accounting for the water-thermal regime of road structures

A lot of works by both domestic and foreign scientists are devoted to the study of the regularities of the water-thermal regime of road structures. The first attempts to theoretically substantiate the processes of moisture accumulation in seasonally freezing soils were presented in the works of S L Bastmanov and N G Shveikovsky. Moisture migration, he believed, is explained by the combined action of molecular adsorption and capillary forces (crystallization forces) that act on the surface of newly appearing crystals. A prominent scientist A F Lebedev experimentally proved that the inflow of film water to the freezing zone occurs even in the absence of ice, for example, in thawed soil, when moisture evaporates from it. He found that film water under the action of molecular adsorption forces moves from thicker to thinner films. The Soviet scientist M P Kudryavtsev [1], based on the results of the study of the water-thermal regime of the subgrade soils, proposed a table of the leading marks of the elevation of the edge of the subgrade above ground level. These studies do not have a scientific methodology for determining the elevation of the edge of the subgrade, but this was the first attempt to provide recommendations for the appointment of the height of the embankment. The water-thermal regime of soils was also devoted to a number of studies by M N Goldstein [2], who put forward the theory of hydration heaving.

Experimental studies carried out by scientists A K Birul, I A Nosich, S G Golovanenko, V M Sidenko [3] found that the most intensive moistening of the subgrade soil from the ditches takes 5-10 days for the first time, and moisture from the ditches has almost no effect on moisture subgrade soil. Research under the leadership of A K Birul became the beginning of an active study of the water-thermal regime and the stability of the roadbed in other regions of the country. The purpose of the observations was, using the early obtained generalized regularities of the water-thermal regime, to investigate the quantitative changes in humidity depending on various natural conditions of the area, for example, such as climate, type of soil, the nature of the area's moisture in the most unfavorable hydrological conditions.

The studies of V M Sidenko made a significant contribution; he developed the theory of moisture accumulation in the upper part of the subgrade and the dynamics of moisture in the subsoil of road pavements in the steppe regions. In addition, he found that soil moisture should be considered as the main indicator when assigning the design strength of soils. To analyze the movement and accumulation of water, V M Sidenko [3] put forward the principle of a differentiated study, according to which the water-thermal regime of road pavements and fabrics is classified into 4 calculated types - diffuse, film, capillary and infiltration. He based the classification on the following distinctive features:

• Sources of humidification (see figure 1).
• The degree of water permeability of the road pavement (presence or absence of cracks in the pavement, and permeable layers in the clothing).
• Distribution of moisture along the depth of the road structure during periods of the year that are unfavorable in terms of moisture.
• The interval of seasonal fluctuations in moisture content, and, consequently, soil deformability.
Currently, there are a number of methods for modeling the processes occurring in the road structure under the influence of natural and climatic conditions. The processes occurring in the roadbed of highways are most fully reflected in the works of Professors V M Sidenko [3], N A Puzakov [4], I A Zolotar [5], etc. Most of the methods under consideration are based on the crystallization-film hypothesis of migration moisture, while the potential theory of molecular mass transfer in the consolidated soil mass is considered basic.

Depending on the sources of humidification, there are 3 calculation schemes:
- Dry areas with a secure runoff of surface waters, deep groundwater levels and low precipitation.
- Areas with sufficient precipitation and difficult surface water runoff. The accumulation of moisture occurs due to the movement of film and capillary-suspended water.
- Areas with a close location of the groundwater level.

A prominent domestic scientist V M Sidenko [3] proposed his own method for calculating the thermal regime of a road structure, which is still relevant today.

Many scientists have worked on the issues of freezing processes modeling, who have made a great contribution to the study of the regional features of the water-thermal regime of highways, such as V A Yarmolinsky [6], V V Lopashuk [6], A V Lopashuk [6], S V Tolstenev [7], I I Leonovich [8], N P Vyrko [8], B S Yushkov [9], A M Burgonutdinov [9, 10] and O A Kosolapov [10].

Thus, there are reliable analytical methods for determining the thermal regime of road structures. Recently, numerical methods have been used to predict the temperature distribution in road structures A M Burgonutdinov [11], K R Kashapova [11], V I Kleveko [11], O V Moiseeva [11], but they all need to determine the temperature in different places of road structures. At the end of the last century, a large amount of factual material was collected to determine the depth of freezing of road pavements and soils and temperatures, which were reflected in the standard temperature. However, in recent years, there have been clear climate changes, therefore, the collection of factual material for determining temperatures at different depths of the road structure is an urgent problem today.

3. Construction of a monitoring system for the temperature of road structures

To collect factual material in order to test the existing methodology for modeling the process of freezing of pavement and subgrade soils. Field studies were carried out to monitor temperature changes at an experimental site located on the territory of the Perm National Research Polytechnic University. The study site is a practically flat (with a minimum slope) asphalted area with a 3 m deep borehole (see figure 2).

A pipe is buried to the entire depth of the well, with temperature sensors built inside the pipe, located with a step of 10 cm (see figure 3).
Figure 2. General view of the well with temperature sensors.

Figure 3. Scheme sensor arrangement for temperature measurement in the road structure.
Temperature sensors are capable of measuring temperature in the range –55 to +125°C, the general view of the device is shown in figure 4.

The total number of temperature sensors was taken to be 32, while sensor 1 is located at the maximum well depth of 3 m, and sensor 32 is located above the level of the asphalt concrete pavement and measures the temperature of the surface air layer (see figure 3).

Temperature sensors transmit information to a personal computer, which is connected to the sensors through a wire and a special unit connected to a personal computer via a USB port. The received data is saved on a personal computer using special software. The program "VM1707.exe" acts as the software. Temperature sensors and software for measuring the temperature in the road structure were developed by LLC "Olymp" (Moscow).

Since November 2019, the monitoring system has been put into operation in test mode. As a result of the measurements, data were obtained showing the average temperature in the road structure depending on the season, as well as a graph of the difference in the average temperature in the road structure in the autumn and winter periods (see figure 5). In this graph, the temperature values of the sensor 32 correspond to the air temperature at a height of 10 cm above the road surface.

The monitoring system has been put into operation in test mode since November 2019. Currently, the accumulation and processing of the obtained data on soil temperature at various depths is underway. So far, the operation of the monitoring system is only possible in manual mode, however, a system for automatic recording of measurement results is being developed. As an example, Figure 5 shows the measurement results showing the average temperature in the road structure depending on the depth for November 2019 and January-December 2020.

Analysis of the obtained values shows that the process of temperature changes at different depths of the road structure is complex. In the process of data processing, several trends were identified:

- Below a depth of 1.3 m from the road surface (sensor 14), the temperature was positive, even in the coldest months.
- Below a depth of 2.6 m (sensor 6), the effect of temperature at the depth of the road structure on the outside air temperature is reduced.

4. Conclusions

1. Based on the analysis of various methods of accounting for the water-thermal regime and the obtained research results, it was revealed that there is a different approach in the design of highways for accounting for the water-thermal regime in road structures.

2. The developed system for monitoring the temperature in the road structure makes it possible to effectively control the temperature values at different depths. However, it is necessary to continue working to improve it.

3. The results obtained in field studies showed that the study of the peculiarities of the operation of the water-thermal regime of road structures is an important, but at the same time, laborious task, the solution of which is possible only under the condition of close cooperation of scientists, designers and builders.
4. The results of further research will make it possible to develop a territorial regulatory document that allows to optimize technical solutions in the design of highways to assess the depth of freezing and the purpose of structural layers of road pavements.

**Figure 5.** Graph of temperature changes in the road structure by months.
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