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Results of the Study of the Water Regime in the Subgrade of Motor Roads

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ABSTRACT. The article deals with the issue of the water-thermal regime of the road subgrade in the conditions of Uzbekistan. Differential equations are proposed to describe the water-thermal regime of the subgrade of roads atthe deep and close occurrence of groundwater, under side hydration.

KEYWORDS: soil, moisture content, subgrade, hydration, strength, deformation, pavement, groundwater, capillary rise, water balance.

I. INTRODUCTION

At present, the traffic intensity on highways is rapidly increasing. This leads to an increase in the load on the pavement and subgrade. Road pavement and subgrade,as the elements of the environment, are influenced by natural and climatic conditions. The water-thermal effect is reflected in the form of cyclic hydration, freezing and drying of the subgrade soil; as a result, the strength characteristics of the subgrade soil working layer change and various deformations occur in the subgrade under waterlogging which ruin the pavement integrity. Deformations and fractures in the subgrade reduce the service life of the pavement and greatly affects the safety of the traffic on highways [1].

II. FEATURES OF THE SYSTEM

To design a subgrade with specified strength properties, it is necessary to forecast the quantitative indices of the water-thermal regime. Analysis of the results of the study, found in literary sources, of the water-thermal regime of the subgrade leads to the conclusion that in an arid zone, especially in irrigated areas, the main source of moistening of the working layer is groundwater, the regime of which is closely related to the irrigation regime. In Uzbekistan, cotton fields are irrigated in summer. The hydration mechanism is associated primarily with capillary rise and side hydration. The diagram given below can be used to describe the subgrade condition in the areas with arid climate (Figure 1).

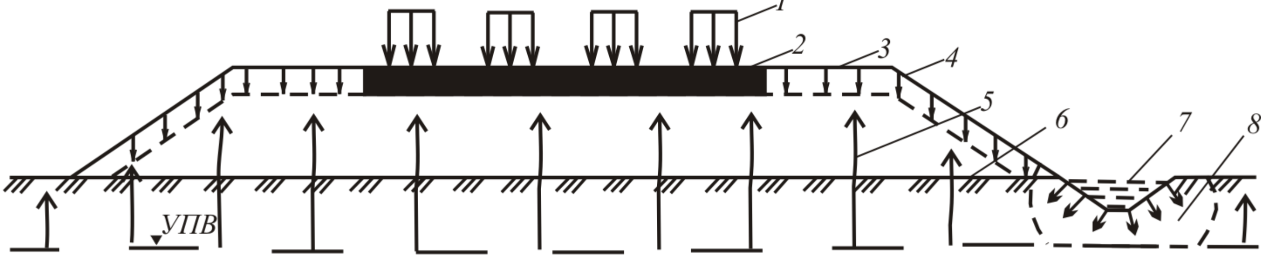

***Fig1*. Scheme of hydration and loading of the subgrade working layer**

1-load from the car wheels; 2-road pavement; 3-roadside; 4-precipitation waters; 5-capillary waters; 6-undisturbed soil; 7-collector; 8- water leaking from the collector.

The analysis of road sections in terms of moisture conditions according to the scheme in Fig. 1 makes it possible to substantiate the thermal and moisture effects on road structures in artificially irrigated areas. As a result of the analysis of Fig. 1, theoretical methods for calculating the water-thermal regime were substantiated and differential equations of the water-thermal regime were derived.

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III. ANALYSIS OF LITERARY SOURCES

Differential equations for the water-thermal regime of the road subgrade underthe deep moistening. For road sections with the deep occurrence of groundwater, the general theory of heat and mass transfer, developed by A.V.Lykov [2] for capillary porous bodies and elaborated by V.M.Sidenko for road structures [3], can be applied. The process of heat and water migration (heat exchange) in the subgrade, provided that the soil is homogeneous, can be represented as follows:

$$\frac{\partial t}{\partial T} = \alpha \frac{\partial^2 t}{\partial z^2} + в \frac{\partial W}{\partial T}, \quad (1)$$

$$\frac{\partial W}{\partial T} = \alpha_1 \frac{\partial^2 W}{\partial z^2} + \alpha_1 в_1 \frac{\partial^2 t}{\partial z^2}. (2)$$

where α is the coefficient of thermal diffusivity of soil, m^2/h; $в$is the coefficient characterizing the heat release or absorption by soil due to phase transformations of water, deg.; α_1 is the coefficient of moisture conductivity of two-phase soil fluid, m^2/h; $в_1$is the thermomigration coefficient 1/h;z is the depth (a variable coordinate), m; t - time, h.

For the case under consideration, there are boundary and initial conditions:

formoisture:

$$W(Z;0) = W_H, \quad W(0,t) = W_H + m_1 t, \quad \left.\frac{\partial W}{\partial Z}\right| = 0 \, (3)$$

for temperature:

$$T(Z;0) = T_H, \; T(0,t) = T_H - m_2 t, \quad \left.\frac{\partial T}{\partial Z}\right| = 0 \, .(4)$$

where W_H, T_H are the initial distributions of moisture and temperature over depth;
m_1, m_2 are the coefficients characterizing the intensity of changes in moisture content and temperature during the cold period. Here m_1= 1/h and m_2 = deg./h.

IV. METHODOLOGY

As a result of the analysis and some mathematical transformations, the final expressions for determining the temperature and moisture content of the subgrade are:

$$W(Z,t) = W_H + m_1 t + \frac{\sqrt{\pi}}{2}\sqrt{\frac{\alpha}{\alpha_1}}\left(1 + \frac{2b_1\alpha_1 m_2 t}{\sqrt{\pi}(\alpha - \alpha_1)}\right) erf\left(\sqrt{\frac{\alpha}{\alpha_1}}\frac{Z}{2\sqrt{\alpha t}}\right) - \frac{\sqrt{\pi} b_1 \alpha_1 m_2 t}{2(\alpha - \alpha_1)} erf\left(\frac{Z}{2\sqrt{\alpha t}}\right)$$

$$T(Z,t) = T_H - m_2 t[1 - erf(\eta)] \, (5)$$

Where $\eta = \frac{Z}{2\sqrt{\alpha t}}$.

Observations have shown that t ranges from 1 to 4 months. Therefore, the values of m_1 range from $1 \cdot 10^{-5}$ to $5 \cdot 10^{-5}$ 1/h. The coefficients of temperature conductivity a, moisture conductivity a_1 and thermal moisture conductivity$в_1$ were obtained from laboratory studies [4].

In the case under consideration, the following values of the coefficients were taken:a= 0.001 deg./h, $a_1 = 7 \cdot 10^{-5}$ $m^{2/}$/h, m_1=$2.5 \cdot 10^{-3}$ m^2/h,$в_1$ = 0.002 1/deg., W_H=0.16, Z=0.2, t=700 h. The distance from the bottom of the pavement to the regular level of groundwater (RLGW) in the area under study is 3 m. The value of $W(Z,t)$according to formula (5) is 0.17.

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Differential equations for the water-thermal regime of the road subgrade undersidehydration. Let us consider the problem of water exchange in a subgrade without an account for thermal and moisture conductivity in the presence of side collectors that affect the change in moisture in the subgrade. The moisture distribution equation is:

$$\frac{\partial W}{\partial t}=\alpha_1\frac{\partial^2 W}{\partial z^2} \quad (6)$$

The initial condition is $W(Z,0)=W_H$, the boundary conditions are:

$W(z, 0)=W_H$; $W(0, t) = W_1$; $W(l, t)=W_H + mt$.(7)

where: l is the distance from the bottom of the pavement to the groundwater level during the period of its maximum stand, m.

Let us introduce a self-similar variable and after some mathematical transformations, the final expression for determining the temperature and moisture content of the subgrade is:

$$W\left(Z,t\right)=(W_H-W_1+m_1t)\frac{erf\left(\frac{Z}{2\sqrt{\alpha_1 t}}\right)}{erf\left(\frac{l}{2\sqrt{\alpha_1 t}}\right)}+W_1 \quad (8)$$

Equation (8) shows that the moisture near the side source of hydration increases and reachesthe maximum value W_H+mt.

The values of the coefficient m for the pockets of water in the side ditches were preliminarily analyzed. The values of $m$were calculated by the following formula:

$$m=\frac{W_K-W_H}{t}, \quad (9)$$

where W_K, W_H are the final and initial soil moisture contents under the edge of the roadway for a period of t hours of water stand in the collectors.

Observations have shown that t ranges from 1 to 6 months. However, the period of water stand of theRLGWis from 1 week to 1 month. Accordingly, the values of m_1 range from $1\cdot10^{-5}$ to $5\cdot10^{-5}$1/h. The coefficients of thermal diffusivity a, moisture conductivity a_1 and thermal moisture conductivity $в_1$ were taken according to laboratory research data [2]. The width of the roadsides in the area under study is 2-2.5 m.

In the case under consideration, the following values of the coefficients were taken: $a_1 = 2\cdot10^{-5}$ m²/h, $m_1=2\cdot10^{-5}$ m²/h, $в_1 = 0.002$ 1/deg., $W_H=0.24$, $W_1=0.32$, $Z=0.2$, $t=200$ h, $l=3$ m.The value of $W(Z,t)$according to formula (8) is 0.25.

To ensure the specified strength of the roadway in areas with long-term wastewater stand, it is necessary to remove the edge of the pavement at a certain distance l from the side collectors. To determine the minimum distance of side collectors from the edge of the roadway, it is necessary to perform appropriate transformations (8). For $t=t_P$, $W(Z,t)=W_P$ we determine l:

$$l=0.8Z\left(W_H-W_1+mt_P\right)+2\pi\sqrt{\alpha_1 t_P} \quad (10)$$

Analysis of expression (10) made it possible to determine the minimum distance between the edge of the roadway and the side collector.

If we take the following values $Z=1.0$ m, $W_H=0.16$, $W_1=0.21$, $m=5x10^{-5}$ 1/h, $t_P=2010$ h, $\alpha_1=8x10^{-5}$ m²/h, then l is obtained in the form:

$$l=0.8x1.0\left(0.16-0.21+0.00005x2010\right)+2x3.14\sqrt{0.00008x2010}=2.56м.$$

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V. RESULTS OF STUDIES

As a result of intensive leaching of fields, and difficult drainage, there is a sharp rise in the groundwater horizon (GWH) and a long period of water stand. During this period, there is a significant risk of a gradual increase in waterlogging of the subgrade soils [5,6].

Since the moisture content of soil in the considered zone is relatively high, the main form of migration is the liquid phase [7]. In this regard, the thermal diffusion of water vapor can be ignored and the equation for water exchange takes the form given in (6).

Analysis of the subgrade service in the area understudy allows us to accept the following boundary conditions:

$$W(Z;0)=W_1; \quad W(0,t)=W_1+mt; \quad W(h,t)=W_0; \qquad (11)$$

where W_0 is the total moisture capacity; W_1 is the initial moisture content, m is the coefficient characterizing the intensity of moisture growth in soil of the subgrade under the roadway; h is the distance from the bottom of the pavement to the groundwater level during the period of its maximum stand.

To solve (6), taking into account (11), we can write the following equations of moisture exchange in the subgrade with a close occurrence of groundwater:

$$W(Z,t)=W_1+mt\left[1-\frac{erf\left(\frac{Z}{2\sqrt{\alpha_1 t}}\right)}{erf\left(\frac{h}{2\sqrt{\alpha_1 t}}\right)}\right]. \qquad (12)$$

To determine the moisture content of soils under the pavement with the close occurrence (1-1.5 m) of the groundwater level, a calculation of $W(Z,t)$ was performed according to equation (12).

Observations have shown that t ranges from 1 to 3 months [8]. However, the period of the RLGW stand is from 1 to 2 months. Therefore, the values of $m_1$range from $2\cdot10^{-5}$ to $7\cdot10^{-5}$1/h. In the case under consideration, the values of these coefficients are a_1 = $2\cdot10^{-5}$ m^2/h, m=$2\cdot10^{-5}$ m^2/h, W_1=0.16, Z=0.2, t=700 h, h=1.2 m.Then the value of $W(Z,t)$according to formula (12) is 0.17.

VI. CONCLUSIONS AND RECOMMENDATIONS

To improve the water-thermal regime in the active zone of the subgrade and to increase its strength, it is important to raise the bottom of the pavement above the calculated groundwater level. When solving the problem, we use equation (12). After simplification, we obtain the following formula:

$$W(Z,t)\Big|_{t\to\infty}=W_1-m\sqrt{t}\,\frac{h-Z}{2\sqrt{\alpha_1}}-\frac{Zh}{4\alpha_1} \qquad (13)$$

The value of h can be determined from formula (13) by an approximate method.

Depending on m, t, α, W_P,W_1 , the value of h ranges from 0.6 to 1.2m.

Thus, an analytical solution for moisture exchange was obtained; $W(Z,t)$ was determined in the subgradewith the deep and close occurrence of groundwater [9]. Besides, an analytical solution was obtained for moisture exchange in the subgrade under soil hydration from the side collectors. For a specific example, the values of $W(Z,t)$ were defined.

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