UDC 669.712.002.68:625

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THE MODEL OF FRAGMENTED BASE COURSE LAYER FOR HEAVY AND INTENSE TRAFFIC

Background. Researches on road pavement condition show that standard types of road bases made of crushed stone do not provide shear resistance and road pavement structure strength under heavy and intense traffic. Such road bases causes formation of ruts, waves, road subsidences, separate cracks and crack network and are responsible for decrease in life expectancy and failure of the road pavement.
Results and conclusions. The analysis of available road bases for asphalt concrete pavements is performed. New constructional decision of fragmented load-bearing layer, which reduces rut and crack formation in pavement, is proposed. Mathematical model describing deflected modes of fragmented load-bearing three-layer road base is suggested.

Keywords: uniformity, theory of plates with cuts, discontinuous functions, fragmented load-bearing layer.

Introduction

Researches on road pavement condition show that standard types of road bases made of crushed stone do not provide shear resistance and road pavement structure strength under heavy and intense traffic.

Such road bases causes formation of ruts, waves, road subsidences, separate cracks and crack network and are responsible for decrease in life expectancy and failure of the road pavement.

The results of experimental researches carried out by A. P. Kuznetsov [1] and B. N. Karpov [2] show that decrease in uniformity of rigid pavements is greatly influenced by uncontrollable crack formation in load-bearing layers and decreasing uniformity of contact of load-bearing layer with lower discrete layers (particularly when using composite road bases).

To reduce crack formation in asphalt concrete pavements, road bases of low-cement (poor) concretes compacted by rollers came into practice in 70^s. To improve physico-chemical indicators of poor concrete, plasticizing additive — bitumen emulsion — is introduced into concrete mix [3]. Prolonged observations on asphalt concretes showed that cracks formed on the bases from poor concrete without joints [4]. Poor concrete has increased rigidity, which predetermine the development of residual temperature deformations. To reduce crack formation, builders began to use crushed-stone layers soaked with cement-sand mortar when laying bases. This provides the means of reducing the stress on the contact of crushed stone particles, increasing the shear resistance and strength of the road structure. Cement-sand mortar, red bauxite sludge, granulated blast-furnace slag, limestone chippings after previous heat treatment are recommended as structure forming materials [1].

To increase the life expectancy, road structures should have coefficient of variation on uniformity 10–20 % for city highways and streets and for district streets, respectively. To say, road required the most resources should have the least coefficient of variation.

It is quite obviously that for the purpose of increasing the life expectancy of road structures for heavy and intense traffic it is necessary to optimize the physicochemical and design characteristics of adjoining layers (asphalt concrete and modified cement concrete) and reduce intensity of crack formation on road surfacing.

It also necessary to design alternative structures of load-bearing layers with controllable rigidity in contact systems, providing for their increasing stability on lower subbase courses, decreasing crack formation on asphalt concrete pavement, and, as a consequence, increasing life expectancy of road structure.

For the purpose of improving the damping properties of load-bearing layers on different subbase courses it is crucial to take into account the size and forms of the elements, as well as characteristics of joints of load-bearing structure elements.

To make alternative design decision, we applied the theory of calculation of designs with various disturbances in uniformity, such as cracks, cuts, etc. Available numerical methods give, as a rule, approximate picture of load distribution in the places of disturbances in uniformity and do not take into account stress concentration.

To select mathematical model, describing the operation of road base, we consider physical statement of the problem.

Examined load-bearing road base consists of three layers. Bottom and upper layers consists of crushed stone-sand cement-strengthened layer in accordance with State

Standard (ГОСТ) 23558-94, middle layer consists of crushed stone-sand layer in accordance with State Standard (ГОСТ) 25607-94. Scheme of fragmentation of the load-bearing base is shown in figure.

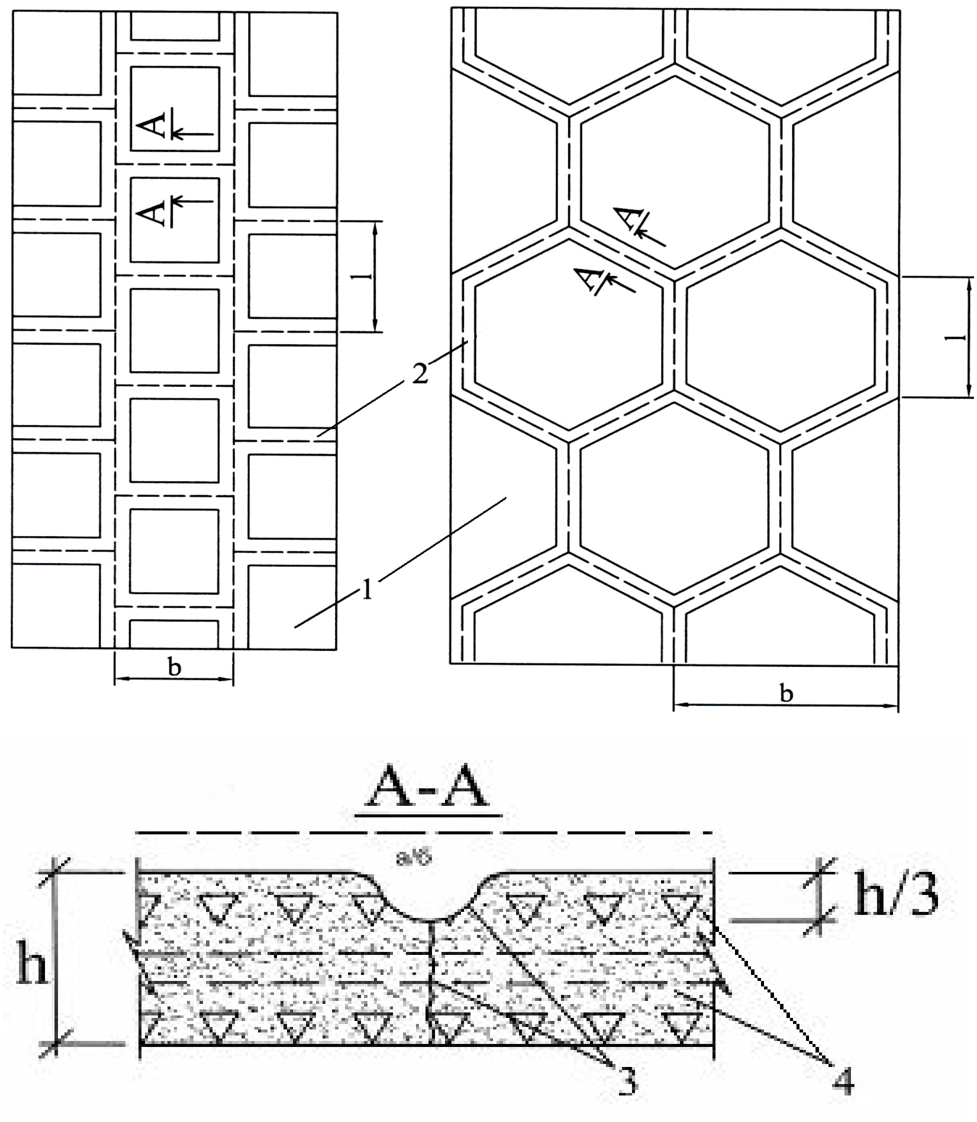

Fig. Scheme of load-bearing base fragmentation:
1 — bearing fragment of the plate; 2 — rustication grooves, weaken sections of the plate;
3 — diameter of the weaken section (rustication groove and weaken sections);
4 — concrete frame in load-bearing layer;
l — side of bearing fragment; а/б — asphalt concrete surfacing

According to the Fig., design model of the base consists of the slabs with cuts of the upper layer of the bearing base. This slab is located on the resilient flexing layer. As a first approximation, assume that value of base reaction is in direct proportion with deflection (Wincler's model), then differential equation of slab deflection can be written in the form

$$\frac{\partial^2 M^*_1}{\partial x^2} + 2\frac{\partial^2 H^*}{\partial x \partial y} + \frac{\partial^2 M_2^*}{\partial y^2} = \rho - \lambda\omega, \qquad (1)$$

where ω is the deflection; $M_1^* M_2^* H^*$ are bending moment and torque with rustication grooves in direction of axes OX and OY.

If it is remembered that fractures, i. e., flexible hinges, are formed along the lines of the hollows , in accordance with [6] slopes of the tangent to the deformed surface of the slab in direction of the axes OX and OY should be presented in the form

$$\gamma_1^* = \gamma_1 + \Delta\gamma_1 H_x;\ \gamma_2^* = \gamma_2 + \Delta\gamma_2 H_y, \qquad (2)$$

where

$$\gamma_1 = \frac{\partial\omega}{\partial x}; \gamma_2 = \frac{\partial\omega}{\partial y}$$

are the slopes of the tangent to the deformed surface on the areas without fractures, $\Delta\gamma_1$, $\Delta\gamma_2$ — angles of fractures;

$$\mathrm{H}_x = \mathrm{H}(x - x_1),\ \mathrm{H}_y = \mathrm{H}(y - y_1)$$

are the unit functions of Heavyside.

With the use of special transformations [7] Eq. (1) is reduced to the system of ordinary differential equation with constant coefficients.

In the first approximation for the case of fractures of the same direction we have

$$(\frac{d^2}{dx^2} - \beta^2{}_1)^2\omega_1 + \frac{\lambda}{D}\omega_1 = \frac{P}{D} - \sum{}^1(\delta^{11}{}_{xi} - \beta^2{}_i\delta_{xi})\Delta\gamma_{i1}. \qquad (3)$$

The solution of the equation is

$$\omega_1 = \omega^0{}_1 + \omega_1^*, \qquad (4)$$

where $\omega^0{}_1$ is the total solution of homogeneous equation

$$(\frac{d^2}{dx^2} - \beta^2{}_1)^2\omega^0{}_1 + \frac{\lambda}{D}\omega_1^0 = 0; \qquad (5)$$

$$\omega^*{}_1 = \omega_{11}{}^0 + \sum\ \omega_{i2}{}^*$$

is the sum of particular solutions of Eq. (3) in accordance with the form of the right side.

If correlations for three-layer bearing plates are used for transformations, resolving equation will have the form

$$2D(h+\frac{t}{2})^2\Delta^2\omega+(1-\frac{Bh}{G_3}\Delta))2D\Delta^2\omega=$$
$$=P-\lambda^4\omega-\sum(\Delta\gamma_{1i}\delta_{xi}{}^{11}+\Delta\gamma^{11}{}_{1iy}\delta_{xi})-\sum(\Delta\gamma_{2j}\delta^{11}{}_{yj}+\Delta\gamma^{11}{}_{2jx}\delta_{yj}), \quad (6)$$

where $B=\frac{Et}{l-\mu^2}$ is the tensile and compression stiffness of one of the extreme layers; t is the thickness of the extreme layers; D is the flexural stiffness of the extreme layer:

$$D=\frac{Bh^3}{l2(l-\mu^2)}; \quad (7)$$

G_3 is the modulus of shearing of the internal layer.

Similar dependencies are obtained for single-layer slab [7].

Hence, in accordance with basic principles of the theory of lamellar systems with discontinuous parameters sought components (shifts, angles of rotation, stresses, moments) are presented with the use of linear combinations of regular and discontinuous functions. This method of calculation of load-bearing layers of road structures based on the theory of plates with regular cuts provides for reduction of solutions to the rather simple algorithms and programs suitable for practical application.

To implement proposed models, algorithm of calculation is developed. The algorithm consists of the following stages:

- compiling of linear combinations of regular and discontinuous functions and determination of the function of the bearing layer deflection;
- determination oof the values of the functions of deflection on the lines of weaken sections;
- set up and solution of equation system for the angles of rotation on the lines of weaken sections;
- determination of deflections of the plate with cuts;
- determination of bending moments and torques, components of deflected mode.

The results of calculations show that for the purpose to increase strength of road structure with three-layer bearing base and to provide for reliability of its operation, it is feasible to divide high-rigid bearing base into elements of the same form (close to the ring) and sizes providing gor increase in uniformity of deformation of the layer under asphalt concrete surfacing and in crack resistance accordingly.

The analytical solution obtained in the result of calculations on proposed theoretical basis with the use of known hyperbolic and trigonometric functions allowed us to build the functions of distribution of deflection, angles of rotation, bending moments in single-layer and three-layer bearing base with cuts depending on specified force action, physico-mechanical and technological parameters of road structure.

Summary

Proposed technique of calculation and optimization of design decisions allowed us to consider the dependence of critical load on physico-geometrical parameters of the bearing layer, sizes and location of the lines of cuts-fractures, their rigid characteristics, which provides a possibility of substantiating practical recommendations for rational design of the elements of bearing layer.

Decision on feasibility of the bonding of cuts-fractures involves division of the layer on hexagonal bearing elements with formation of tri-radial intersections providing for increase in local (vertical) stability of the area of cuts and total (longitudinal) stability at the cost of transformation of linear deflection mode in the plane one on longitudinal load.

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