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ENSURING ADHESION BETWEEN THE ASPHALT-CONCRETE ROAD SURFACE AND RIGID BASE AT THE ROADBED DESIGN STAGE

Yevhen Dorozhko
Corresponding author
PhD, Associate Professor*
E-mail: evgeniy.dorozhko@gmail.com
Angelika Batrakova
Doctor of Technical Sciences, Professor*
Vladislav Tymoshevskyi
PhD, Associate Professor*
Elina Zakharova
Assistant*
*Department of Road Design, Geodesy and Land Management
Kharkiv National Automobile and Highway University
Yaroslava Mudroho str., 25, Kharkiv, Ukraine, 61002

Arranging asphalt-concrete layers on a rigid base in the form of cement-concrete slabs can significantly improve the transporting and operational performance of the road surface. Such a structural solution is appropriate in almost all countries of the world since cement-concrete slabs retain high strength for a long time. To prevent the rapid destruction of an asphalt-concrete road surface on a rigid base, it is necessary to ensure reliable adhesion between the layers' contacts and, at the design stage, to test the adhesion strength by estimation.

This paper has substantiated a criterion of adhesion strength in the contact between an asphalt-concrete road surface and the rigid base. The calculation involves comparing the active tangent stresses in the contact between layers dependent on the effect of the vertical and horizontal components of the transport load with the magnitude of permissible tangent shear stresses in the contact of layers.

The parameters for an estimation model have been established; the stressed-strained state of the roadbed structure has been simulated using a finite element method. When modeling the stressed-strained state and calculating based on the strength criterion, different vehicle traffic conditions have been considered, as well as the effect of temperature on the strength parameters of the asphalt-concrete layer and the tar layer. The conditions for vehicle movement, taken into consideration when designing, correspond to the conditions of movement along the road, along the curves in the plan and profiles, and notion conditions at car emergency braking. Practical recommendations have been compiled for assigning the minimum permissible thickness of an asphalt-concrete layer on a rigid base, which must be followed at the design stage due to the condition for ensuring reliable adhesion between the layers' contacts. The minimum permissible thickness ranges from 2 cm to 10 cm, depending on the conditions of movement, temperature, and the type of tar

Keywords: asphalt-concrete layer, elasticity module, stressed-strained state, adhesion, cement-concrete slab

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1. Introduction

In most countries of the world, a common technology for constructing motorways involves a roadbed of the rigid type in the form of cement-concrete slabs [1]. Cement-concrete slabs have a longer service life between major repairs compared to an asphalt-concrete road surface, however, there comes a time when cement-concrete slabs need repair. In most cases, cement-concrete slabs retain high enough strength and only require improvements in their evenness, roughness, as well as repair of deformation joints between the slabs [2].

Roadbed in the form of cement-concrete slabs presents difficulties when executing repair work, so quite often such structural solutions are used that involve covering slabs with a thin asphalt-concrete layer [3]. This technology makes it possible to quickly and efficiently improve the transporting and operational indicators of cement-concrete slabs. In this case, the asphalt-concrete layer acts as a protective layer or the wear layer on cement-concrete slabs. The combined slab made in this way is characterized by a high bearing capacity due to the cement-concrete slab at its base, comfortable driving conditions, and the relative ease of repair work owing to the asphalt-concrete layer. For such structures, it is necessary to ensure the strength of the asphalt-concrete layer of the roadbed since the road surface state depends on it.

The most common deformations and destructions inherent in the combined slabs include the shear and detachment of an asphalt-concrete road surface from the rigid base, caused by the loss of adhesion at the contact of layers [4]. Given this, it is a relevant task to undertake a study aimed at ensuring the reliable adhesion of the contact of an asphalt-concrete layer on a rigid base at the stage of roadbed design.

2. Literature review and problem statement

Paper [3] reports an analysis of the practical operation of asphalt-concrete layers on a rigid base abroad. The results of observing the experimental sections of roads established the most common deformations and destruction of asphalt-concrete road surface on a rigid base. Most often, asphalt-concrete road surface undergoes destruction in the form of reflected cracks over the temperature seams of cement-concrete slabs, as well as destruction caused by loss of adhesion between layers. The reported conclusions coincide with the findings described in work [4], which states that under the condition of unsecured adhesion between the layers, there is the rapid destruction of asphalt-concrete road surface on a rigid basis due to the action of the transport load. Therefore, it is imperative to take structural measures to prevent the emergence of reflected cracks in the asphalt-concrete road surface above the temperature seams of cement-concrete slabs and provide for reliable adhesion between the layers.

Study [5] confirms the need to ensure reliable adhesion between the asphalt-concrete layer and a rigid base in the form of a bridge structure, as well as the feasibility of taking measures to prevent the emergence of reflected cracks. According to work [6], one of the most successful measures to eliminate the reflected crack formation is the method for arranging deformation joints in an asphalt-concrete coating over the seams of cement-concrete slabs. Thus, the design of the roadbed is cut into combined slabs that work separately from each other. However, works [3–6] do not consider the procedure for assessing the strength of the adhesion in contact between the asphalt-concrete road surface and rigid base. Paper [6] also substantiated the need to take into consideration the horizontal component induced by the transport load arising from traction force or emergency braking.

Study [7] found that the existing strength criteria did not sufficiently meet the most common mechanisms of destruction of asphalt-concrete road surfaces on a rigid base. None existing estimation method provides for the verification, according to the strength criterion, of the contact between the asphalt-concrete layer and cement-concrete slab in terms of adhesion. The calculations do not take into consideration the horizontal force arising from traction force or braking of the car. Similar conclusions are drawn in paper [8], which reports a study into the working conditions for asphalt-concrete layers on a rigid base and determining appropriate strength criteria. It is noted that under the condition of unsecured adhesion of layers, there is the rapid destruction of the asphalt-concrete road surface due to the effect of a horizontal force. Therefore, when designing asphalt-concrete layers for road surfaces on a rigid base, it is advisable to check if the adhesion between layer contacts is ensured.

Study [9] tackles determining the most common mechanisms of destruction of the asphalt-concrete road surface layers and establishing their cause. In addition, the analysis of the stressed-strained state of the asphalt-concrete road surface layers on a rigid base was performed for different options in the location of the transport load relative to the edges of a cement-concrete slab. When modeling the stressed-strained state of asphalt-concrete road surface, work [9] considers only the vertical pressure from vehicles while the horizontal force is neglected. The results in the cited work lack recommendations on the strength of the asphalt-concrete road surface, which could prevent destruction.

The above gives reason to assert that it is advisable to conduct a study to analyze the stressed-strained state in the contact between the asphalt-concrete road surface layer and the rigid base and devise a procedure for checking if reliable adhesion between the layer contacts is ensured. That could prevent the premature destruction of an asphalt-concrete road surface, extend the roadbed service life, and reduce the cost of non-scheduled repairs.

3. The aim and objectives of the study

The purpose of this study is to identify patterns in the formation of the stressed-strained state in the contact between an asphalt-concrete layer and a rigid base under different driving conditions, which would make it possible to devise recommendations for designing the road surface asphalt-concrete layers on a rigid base under the condition of ensuring reliable adhesion.

To accomplish the aim, the following tasks have been set:

– to model numerically the stressed-strained state of a roadbed structure by a finite element method for different traffic conditions;

– to determine the minimum permissible thickness of an asphalt-concrete layer on a rigid base under the condition of ensuring reliable adhesion at layer contacts for different types of tarring and traffic conditions.

4. The study materials and methods

4. 1. Substantiating the criterion of adhesion strength in the contact between an asphalt-concrete road surface and the rigid base

The strength of the material under any strained state would be disrupted when the magnitude of the most dangerous factor reaches its limit value [10]. Under the action of transport load and temperature deformation, the loss of interlayer adhesion between the asphalt-concrete road surface and a cement-concrete slab is possible since tangent stresses act in the layer contacts [5, 6, 11]. When an asphalt-concrete layer is arranged and compacted on a cement-concrete slab, there is no overlapping of the mineral frames of the asphalt-concrete layer and the cement-concrete slab. The adhesion between layers occurs due to the binder film. In this case, the grip forces are due to adhesion – sticking the binder to the surface of layers of the mineral material, and cohesion – the strength of the binder in thin layers [5, 6].

The condition of strength in the layer contacts can be violated for several structural and technological reasons. The structural reasons include [11–13]:

– irrationally selected structural layers (the asphalt-concrete elasticity module, tarring type, layer thickness). As a result, significant shear stresses occur in the plane of the layers' contacts;

– the structure and composition of asphalt-concrete (mineral composition, bitumen grade) do not provide the necessary shear resistance in layer contacts.

The technological reasons include [11–13]:

– the use of low-binding bitumen for tarring, reducing the shear resistance of the asphalt-concrete layer in the contact area between layers;

– clogging of the lower layer, insufficient cleaning of the cement-concrete coating before the asphalt-concrete layer is arranged;

In the latter case, a weakened zone has already been laid in the coating, in which the adhesion of layers is provided mainly only due to friction forces.

We have considered the work of a layered system under the condition that in the plane of layer contacts there was a zone in which there is no adhesion between layer contacts (zone *KL*) in Fig. 1, according to papers [12, 13].

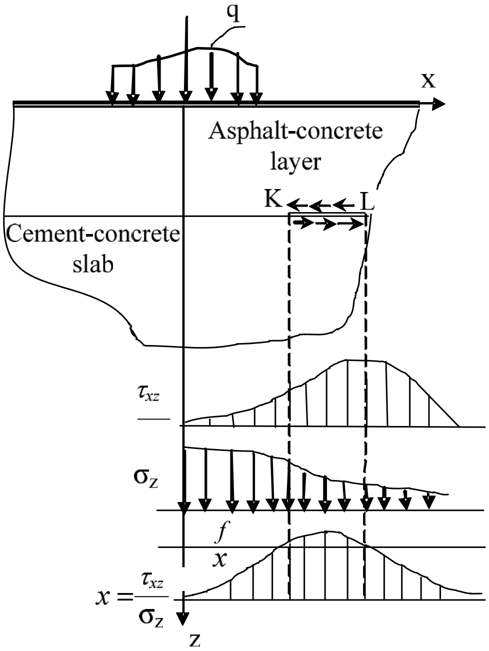


Fig. 1. Schematic crack evolution between an asphalt-concrete layer and a cement-concrete slab

When the transport load *q* is at a distance from the site *KL*, the layers would perform similar to connected ones. This is due to the fact that the tangent stresses τ_{xz} in the contact plane are not able to overcome the friction force, that is, the following condition is met:

$$\tau_{xz} \le K_m \cdot f \cdot \sigma_z, \tag{1}$$

where K_m is the coefficient that takes into consideration the possibility of increasing the shear resistance in case the shear occurs not in the contact zone of the layers but in the asphalt-concrete layer; *f* is the friction coefficient; σ_z is the normal stress, MPa.

During movement, the transport load (*q*) would begin to approach the *KL* zone shown in Fig. 1. In this case, the stress τ_{xz} in the *KL* zone does not coincide in terms of its maximum with the stress σ_z, and condition (1) may be violated. If the loss of adhesion in the *KL* zone crack resulted from a shear with the destruction of elastic bonds (adhesion and cohesion), and condition (1) is not met, a relative shift of the two edges of the crack would occur. At the same time, the stresses τ_{xz} would decrease to zero on the *KL* site, and stresses would be redistributed in the structure. Given the solutions from elasticity theory [14], it is known that at points *K* and *L* the tangent stresses τ_{xz} would increase sharply. The destruction of the material would occur, and the size of the *KL* site would increase. Along with the development of cracks, the surface of the cement-concrete slab and the asphalt-concrete layer would be eventually mated, which could lead to a decrease in the friction coefficient (especially in the case of moisture ingress between the layers). The calculation according to the criterion for ensuring the adhesion in the contact between an asphalt-concrete layer and a cement-concrete slab implies comparing the active tangent stresses in the layer contacts with the shear strength of the contact. The loss of an interlayer adhesion between the asphalt-concrete layer and cement-concrete slab is most likely at the highest possible temperature, since, at this time, the strength of the tarring layer decreases [5, 8]. The criterion of strength in the layer contacts can be recorded as follows:

$$\frac{\tau_{pt}}{\tau_{xz}} \ge K_m, \tag{2}$$

where τ_{xz} is the maximum active shear stresses in the layer contacts due to the action of transport load, MPa; τ_{pt} is the permissible (limit) tangent shear stresses in the layer contacts, MPa; K_m is the coefficient of margin of shear strength in the layer contacts.

4. 2. The estimation model parameters

The designed estimation scheme and the choice of a model of materials are based on the general methods for solving problems related to the mechanics of a deformed solid. The rigid base is adopted in the form of a monolithic cement-concrete slab with temperature seams, in which it is inherent that its module of elasticity and strength does not depend on the temperature, humidity, and duration of the load. The cement-concrete material is adopted as an elastic, solid homogeneous, and isotropic body [2, 15–17].

The rigid base is characterized by:

- the size of a cement-concrete slab in the plan;
- thickness;
- a module of elasticity and a Poisson coefficient;
- a general (equivalent) module of elasticity of the base under cement-concrete slabs.

An asphalt-concrete layer is considered to be a layer with the properties of crushed mastic asphalt concrete arranged atop a cement-concrete slab. According to [9, 10, 18, 19], an asphalt-concrete layer is adopted as an elastic body, that is, it is deformed without residual deformations. For the elastic deformation adopted in our study, such a property of the body model as creep and viscous elasticity [9–11] is completely rejected. This approach is possible because the duration of the transport load is less than 0.1 s, and, during this time, the asphalt concrete does not have time to manifest the viscous-elastic or plastic properties of the material. The structural elements of asphalt concrete are located within the solid at random. Macro defects [9–11] are also distributed in the volume of the material. It is known from [9, 10, 14, 20] that the body that has macro defects can be considered as a quasi-homogeneous system within its base – the matrix. In this case, the idealization of the real environment in relation to its homogeneity, the solidity of isotropy do not lead to fundamental errors in calculations based on general solutions in elasticity theory [9, 18, 20, 21]. The estimation model used to simulate the stressed-strained state of a roadbed structure is shown in Fig. 2.

When modeling, the condition of secured adhesion between the asphalt-concrete road surface layer and the rigid base is accepted. To prevent cracks in the asphalt-concrete layer above the seams of cement-concrete slabs, the estimation model accounts for arranging deformation joints in asphalt-concrete layers above the seams of cement-concrete slabs. Thus, the roadbed structure under consideration is the combined slabs. A combined slab is composed of a cement-concrete slab on an elastic semi-space, atop of which is an asphalt-concrete layer arranged under a condition of adhesion between the asphalt-concrete layer and the cement-concrete slab. We consider the stressed-strained state of the combined plate whose dimensions are limited by temperature seams. The legitimacy of this approach is justified in works [8, 9].

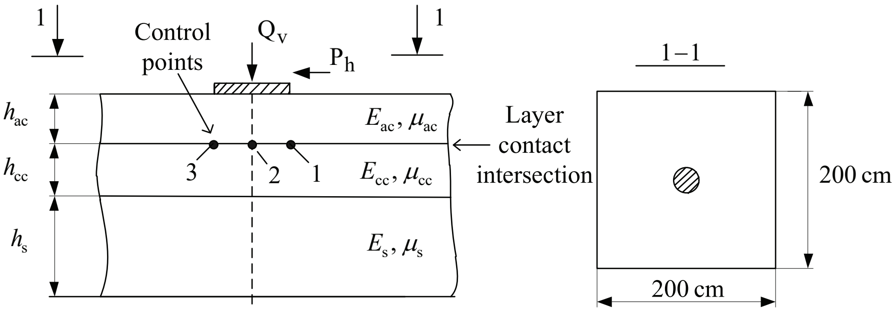


Fig. 2. Estimation model of an asphalt-concrete layer on a rigid base: 1—1 — projection of the model onto a horizontal plane

4. 3. Simulating the stressed-strained state of a roadbed structure by a finite element method

The stressed-strained simulation was performed by a finite element method in the ANSYS software package.

The model's grid is built using elements of a predominantly hexagonal shape. The elements' shape was selected on the basis of works [5, 9, 20, 21]. An example of the estimation model is shown in Fig. 3.

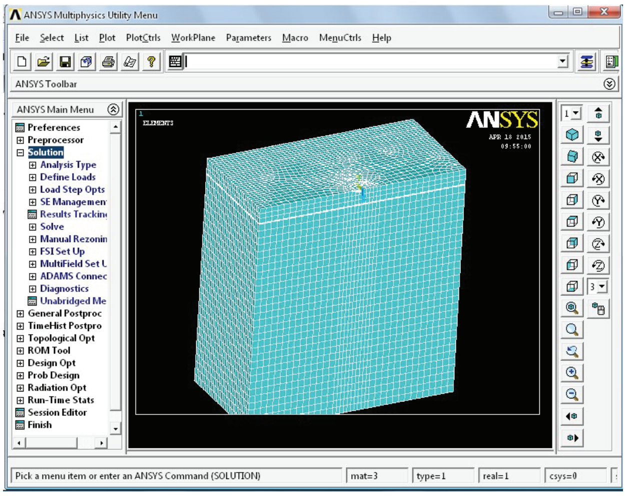


Fig. 3. Estimation model for determining the stressed-strained state of the roadbed structure

The static load is applied using a round press tool whose diameter is equivalent to the imprint of the wheel of an estimated vehicle of group A_2 in accordance with DBN V.2.3-4. The magnitude of the vertical load is 0.8 MPa, the horizontal force is taken in the range from 5 kN (for rectilinear sections along the road) to 45 kN (for emergency braking). The diameter of the press tool is 34.5 cm. In the models:

– the modulus of elasticity and the Poisson coefficient of cement-concrete are constant (E_{cc}=27,000 MPa, μ_{cc}=0.15);

– the thickness of the cement-concrete base varied in the range from 20 cm to 28 cm in increments of 4 cm;

– the thickness of an asphalt-concrete layer is accepted to be 2 cm, 5 cm, 7 cm, 10 cm;

– the modulus of elasticity and the Poisson coefficient of asphalt-concrete varied from E_{ac}=5,000 MPa and μ_{ac}=0.25 to E_{ac}=400 MPa and μ_{ac}=0.4;

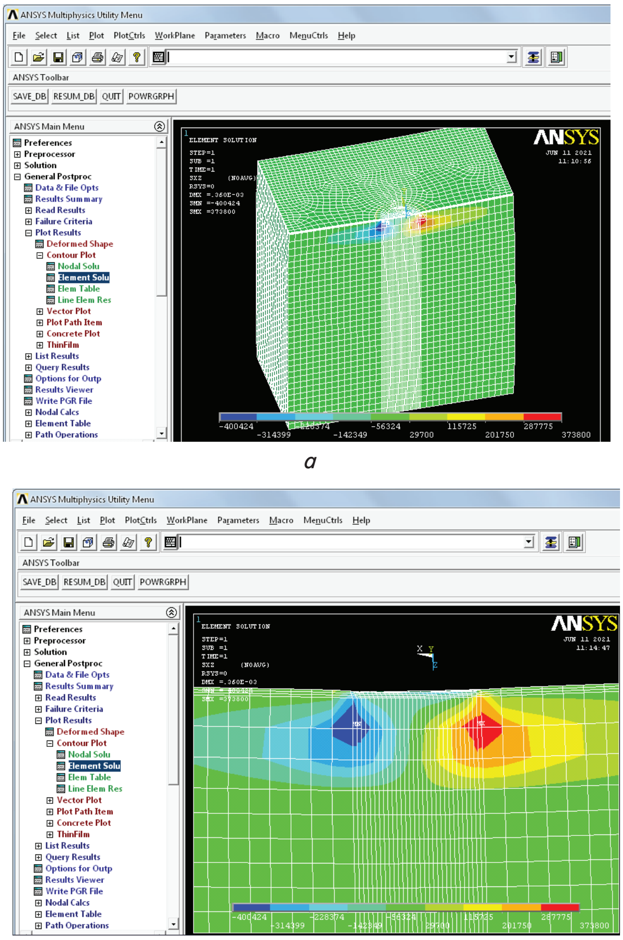
– the total equivalent modulus of elasticity at the surface of the base is 150 MPa, the Poisson coefficient is 0.3.

5. The results of studying the strength of adhesion between an asphalt-concrete road surface and a rigid base at the stage of roadbed design

5. 1. The results of simulating the stressed-strained state of a roadbed structure by a finite element method

The result of simulating the stressed-strained state has established the tangent stresses in the contact between an asphalt-concrete layer and a cement-concrete slab for different conditions of movement and climatic conditions.

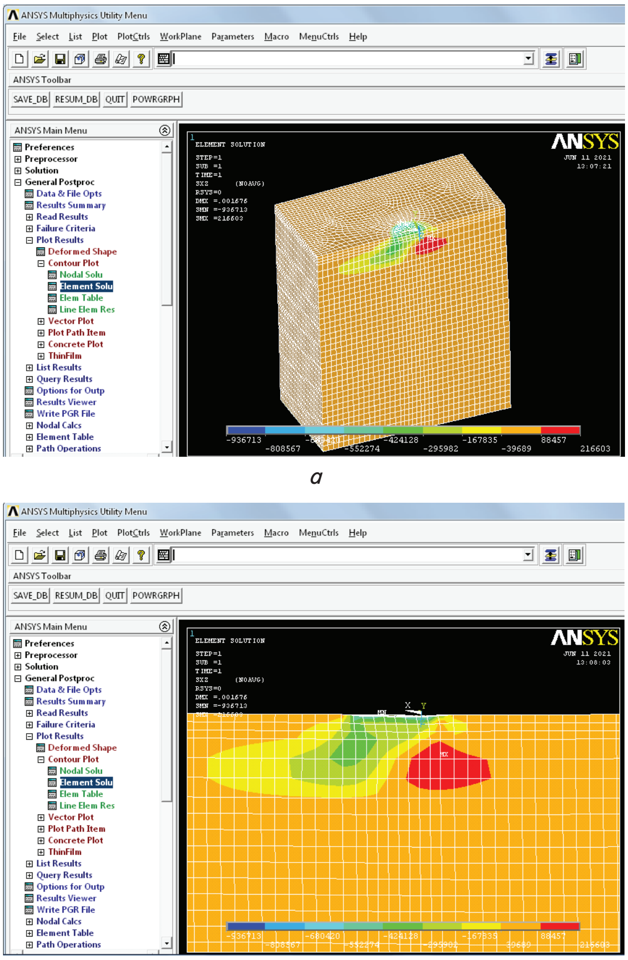
An example of the simulation results is shown in Fig. 4, 5, and in Table 1.



a

b

Fig. 4. The result of determining the tangent stresses τ_{xz} for a model with the thickness and modulus of elasticity of an asphalt-concrete layer of 2 cm and 400 MPa, respectively, the thickness and modulus of elasticity of a cement-concrete slab of 24 cm and 27,000 MPa, respectively, under a vertical load of 0.8 MPa, a horizontal force of 5 kN: *a* — the overall form of the model; *b* — the enlarged image of a model's part under a press tool



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b

Fig. 5. The result of determining the tangent stresses τ_{xz} for a model with the thickness and modulus of elasticity of an asphalt-concrete layer of 10 cm and 400 MPa, respectively, the thickness and modulus of elasticity of a cement-concrete slab of 24 cm and 27,000 MPa, respectively, under a vertical load of 0.8 MPa, a horizontal force of 45 kN: *a* – the general form of the model; *b* – the enlarged image of a model's part under a press tool

Based on the simulation results, it has been determined that when changing the module of elasticity of an asphalt-concrete layer, the tangential stresses in the layer contacts change linearly. To identify this dependence, a search simulation was performed. The thickness of an asphalt-concrete layer in the models was taken equal to 2 cm, 5 cm, 7 cm, and 10 cm; the thickness of a cement-concrete slab was taken equal to 20 cm, 24 cm, 28 cm, with an elasticity module of 27,000 MPa. The models varied only the value of the asphalt-concrete layer elasticity module, which was taken equal to 400 MPa, 1,000 MPa, 1,500 MPa, 2,000 MPa, 2,500 MPa, 3,000 MPa, 3,500 MPa, 4,000 MPa, 4,500 MPa, and 5,000 MPa. In all estimation models, there is a linear dependence of changes in the value of tangent stresses when changing the module of elasticity of the asphalt-concrete layer. The pattern of change in the tangent stresses in the contact between an asphalt-concrete layer and a cement-concrete slab depending on the size of the asphalt-concrete layer elasticity module for one of the models (the thickness of the asphalt-concrete layer is 2 cm, the thickness, and modulus of elasticity of the cement-concrete slab is 24 cm and 27,000 MPa, respectively, the vertical pressure value is 0.8 MPa, the diameter of the press tool imprint is 34.5 cm), used in the search simulation, is shown in Fig. 6.

Table 1

Example of a summary table of the tangent stresses τ_{xz} in the contact between an asphalt-concrete layer and a cement-concrete slab, MPa

Vertical load, 0.8 MPa; press tool diameter, d_p=34.5 cm; horizontal force, 5 kN; E_{ac}=400 MPa; μ_{ac}=0.40; E_{cc}=27,000 MPa; μ_{cc}=0.15; E_s=150 MPa, μ_s=0.3					
cement-concrete slab thickness (h_{ac})	asphalt-concrete layer thickness (h_{ac})				Point location relative to the press tool axis according to Fig. 1
	2 cm	5 cm	7 cm	10 cm	
20 cm	0.206	0.232	0.238	0.213	press tool edge (point 1)
	–0.095	–0.043	–0.033	–0.026	press tool axis (point 2)
	–0.284	–0.290	–0.277	–0.254	press tool edge (point 3)
24 cm	0.204	0.228	0.229	0.209	press tool edge (point 1)
	–0.095	–0.043	–0.033	–0.025	press tool axis (point 2)
	–0.282	–0.287	–0.275	–0.250	press tool edge (point 3)
28 cm	0.202	0.226	0.227	0.206	press tool edge (point 1)
	–0.095	–0.043	–0.033	–0.026	press tool axis (point 2)
	–0.278	–0.285	–0.272	–0.248	press tool edge (point 3)

Based on the simulation results, it has been determined that when the value of the horizontal force changes in the range from 5 kN to 45 kN, the tangential stresses in the contact between an asphalt-concrete layer and a cement-concrete slab change linearly. The thickness of the asphalt-concrete layer and the elasticity module in the models were accepted equal to 2 cm, 5 cm, 7 cm, and 10 cm, and 400 MPa, 1,500 MPa, 3,000 MPa, 5,000 MPa, respectively; the thickness of the cement-concrete slab was taken equal to 20 cm, 24 cm, 28 cm, with an elasticity module of 27,000 MPa. The values of the horizontal force of 5 kN, 10 kN, 20 kN, 30 kN, 40 kN, and 45 kN varied in the models. In all estimation models, there is a linear dependence of change in the value of tangent stresses in the layer contacts when changing the value of the horizontal force, other conditions being equal. The pattern of change in the tangent stresses in the contact between an asphalt-concrete layer and a cement-concrete slab depending on the value of the horizontal force for one of the models (the thickness and modulus of elasticity of the asphalt-concrete layer is 5 cm and 1,500 MPa, respectively, the thickness and modulus of elasticity of cement-concrete slab is 24 cm and 27,000 MPa, respectively, the vertical pressure is 0.8 MPa, the diameter of the press tool imprint is 34.5 cm), used in the search simulation, is shown in Fig. 7.

This dependence holds for the entire selected interval of values for the asphalt-concrete layer elasticity modules and the thicknesses of structural layers. Therefore, linear interpolation can be used to determine the stresses due to the action of the horizontal force in the range of values from 5 kN to 45 kN.

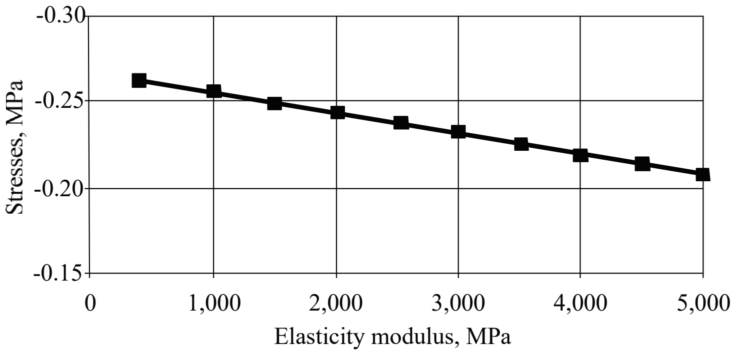

Fig. 6. Dependence of the magnitude of tangent stresses τ_{xz} in the layer contacts on the magnitude of the module of elasticity of an asphalt-concrete layer

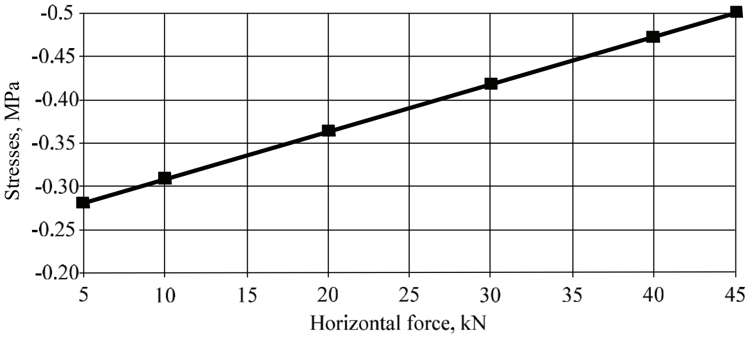

Fig. 7. Dependence of the value of the tangent stresses τ_{xz} in the layer contacts on the value of the horizontal force

5. 2. Determining the minimum permissible thickness of an asphalt-concrete layer on a rigid base

The permissible (limit) tangent shear stresses in the layer contacts, according to [22, 23], can be determined from the following formula:

$$\tau_{pt} = \tau_{ss} \times \left(1 - \nu_{\tau} \times t\right), \qquad (3)$$

where τ_{ss} is the shear strength (the maximum tangent stresses between an asphalt-concrete layer and a cement-concrete slab, determined experimentally according to the procedure given in [22, 24]; ν_{τ} is the coefficient of variation of shear strength; t is the coefficient of deviation variance, depending on the level of reliability of the structure).

For the practical assessment of shear strength in the layer contacts, the values of the active tangent stresses and strength parameters of different types of tarring have been analyzed. To this end, all regions in the territory of Ukraine, under the conditions of asphalt-concrete operation, in accordance with the classification set by DBN V.2.3-4, were divided into three groups according to similar temperature intervals of asphalt-concrete road surface heating:

– group I – regions A_1, A_2, A_3 heated to 53 °C;

– group II – regions A_4, A_6 heated to 55 °C;

– group III – regions A_5, A_7 heated to 57 °C.

The maximum shear strength of the adhesion between layer contacts depends on the temperature in the contact between the layers [5, 8, 13].

The dependence of temperature in the layer contacts on the thickness of an asphalt-concrete layer was determined from formula (4), according to the procedure given in [22]. The results are shown in Fig. 8.

$$t^{h} = t_{am} + \left(\frac{t_{air}^{am\ \max} - t_{air}^{am\ mean}}{2} + \frac{\rho \times I_{sr}}{a_t} \times K_1 \times K_2 \times K_n \right) \times \exp\left(\left(-h_{ac} \times \sqrt{\frac{\omega}{2 \times a_{ac}}} \right) \times \cos\left(\omega \times \tau - h_{ac} \times \sqrt{\frac{\omega}{2 \times a_{ac}}} \right) \right), \qquad (4)$$

where t^{h} is the temperature in the contact between an asphalt-concrete layer and a rigid base, °C; t_{am} is the average monthly air temperature, °C; $t_{air}^{am\ \max}$ is the average monthly maximum air temperature, °C; $t_{air}^{am\ mean}$ is the mean monthly temperature of air, °C; ρ is the coefficient of solar radiation absorption at the surface of the coating; I_{sr} is the mean daily intensity of solar radiation, kcal/m^2×hour×degree; a_t is the heat transfer coefficient, kcal/m^2×hour×degree; K_1 is the coefficient that takes into consideration the weakening of solar radiation at any hour within 24 hours; K_2 is the coefficient of transition from the average daily intensity of solar radiation to the intensity at 12:00; K_n is the dust coefficient (a decrease in the intensity of solar radiation due to dust formation); h_{ac} is the thickness of an asphalt-concrete layer, m; ω is the angular frequency of temperature fluctuations, rad/h; a_{ac} is the thermal conductivity of asphalt-concrete, m^2/h; τ is the point of time from the beginning of the fluctuation period, h.

Fig. 9 shows the dependence of change in the maximum active shear stresses (determined by a finite element method) and the maximum strength of different types of tarring (depending on the temperature and determined according to data in Fig. 8 according to formula (3)) on the thickness of an asphalt-concrete layer. At the intersection point of the curve of values for the maximum active shear stresses with the curve of the maximum strength of tarring, the minimum allowable thickness of the asphalt-concrete layer is determined.

The result of analyzing our calculations has established the minimum permissible thicknesses of an asphalt-concrete layer on a rigid base, which must be considered during the design, to ensure reliable adhesion in the layer contacts.

A value for the minimum permissible thickness of an asphalt-concrete layer has been determined for different types of tarring and different temperature conditions. When a bitumen emulsion is used for tarring, the minimum allowable thickness of an asphalt-concrete layer would be:

– for conditions of movement along the road and curves in the plan, for groups I, II, III, at temperature intervals, – 2 cm;

– for conditions of movement along the sections of emergency braking, for group I based on temperature intervals, – 4 cm; for the conditions of group II based on temperature intervals, – 5 cm; for the conditions of group III based on temperature intervals, – 6 cm.

When surfaced waterproofing insulation is used for tarring, the minimum permissible thickness of an asphalt-concrete layer would be:

– for the conditions of movement along the road, for groups I and II based on temperature intervals, – 2 cm; for the conditions of group III based on temperature intervals, – 5 cm;

– for the conditions of movement along curves in the plan, for group I based on temperature intervals, – 2 cm; for the conditions of group II based on temperature intervals, – 5 cm; for the conditions of group III based on temperature intervals, – 6 cm;

– for the conditions of movement along the sections of emergency braking, for group I based on temperature intervals, – 7 cm; for the conditions of group II based on temperature intervals, – 8 cm; for the conditions of group III based on temperature intervals, – 9 cm.

– for the conditions of movement along the curves in the plan, for group I based on temperature intervals, – 4 cm; for the conditions of group III based on temperature intervals, – 6 cm; for the conditions of group III based on temperature intervals, – 7 cm;

– for the conditions of movement along the sections of emergency braking, for I based on temperature intervals, – 8 cm; for the conditions of group II based on temperature intervals, – 9 cm; for the conditions of group III based on temperature intervals, – 10 cm.

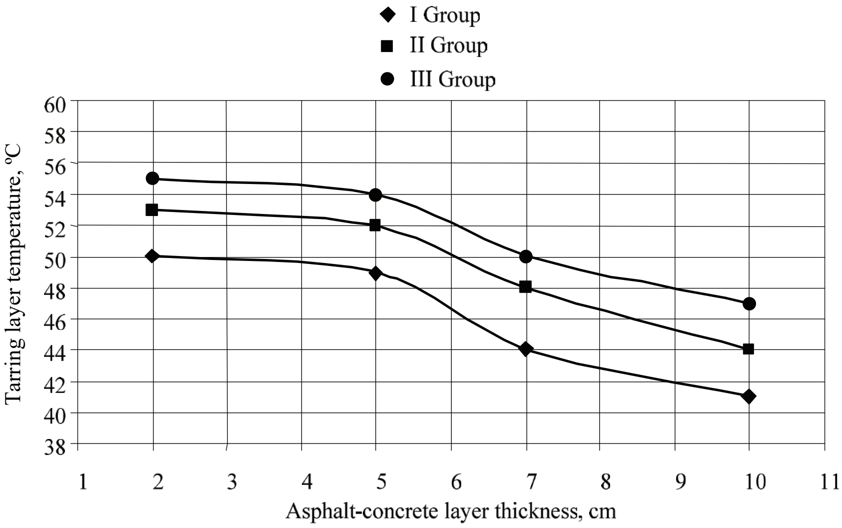

Fig. 8. Dependence of temperature in the layer contacts on the thickness of an asphalt-concrete layer

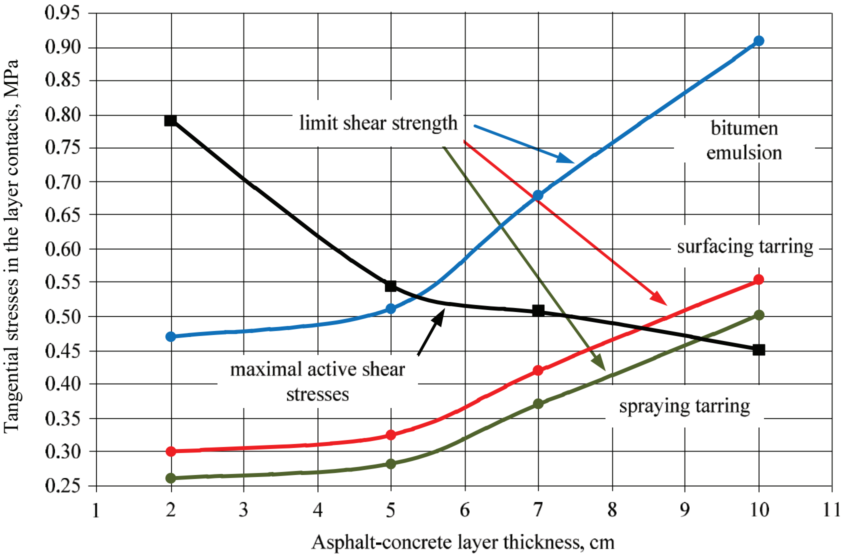

Fig. 9. Strength parameters for different types of tarring for emergency braking conditions (horizontal force, 45 kN) in group III of regions

When using spray tarring, the minimum permissible thickness of an asphalt-concrete layer would be:

– for the conditions of movement along the road, for group I based on temperature intervals, – 2 cm; for the conditions of groups II and III based on temperature intervals, – 6 cm;

6. Discussion of results of simulating the stressed-strained state of a roadbed structure and estimating the strength of adhesion between layer contacts

Based on the results from simulating the stressed-strained state of an asphalt-concrete layer on a rigid base, it was established that:

– an increase in the thickness of an asphalt-concrete layer from 2 cm to 10 cm leads to a decrease in the tangent stresses τ_{xz} in the layer contacts;

– the tangent stresses τ_{xz} increase significantly when the value of the horizontal force increases.

The most dangerous, in terms of the conditions for ensuring reliable adhesion in layer contacts, are the sections of roads with emergency braking conditions, which is obvious given the content in Fig. 7. This is explained by the fact that under the condition of emergency braking there is the greatest value of the horizontal force and, as a result, the maximum value of active tangent stresses in the layer contacts. This conclusion is confirmed by the results of observing the experimental sections in [3, 5, 8] with possible cases of emergency braking (transition-speed lanes, approaches to intersections at the same level, etc.). Along such sections, the delamination and rapid destruction of the asphalt-concrete layer on a rigid base are much more common compared to the sections along a road.

Increasing the thickness of an asphalt-concrete layer on a rigid base leads to a decrease in the likelihood of loss of adhesion in the layer contacts because of the following:

– there is a decrease in the amount of tangent stresses in the layer contacts;

– there is a decrease in temperature in the layer contacts, which, in turn, leads to an increase in the maximum shear strength of the tarring material.

The conclusions from our study could be considered appropriate since they make it possible to substantiate the minimum permissible thickness of an asphalt-concrete layer on a rigid base. These conclusions are applicable for different types of tarring, different movement conditions, and different regions based on temperature conditions.

However, it is impossible not to note that the findings could be used only for the design of roadbed without reinforcement of the transverse and longitudinal seams and for a group of estimation load A_2. This assumption imposes certain restrictions on the use of the reported results, which may be interpreted as a lack of this study. The inability to remove this assumption within the framework of the current study suggests a potentially interesting area of further research. This study could be advanced by taking into consideration the reinforcement of the seams with pins, which would account for the possibility of partial transfer of the load from a slab to a slab.

7. Conclusions

1. The numerical simulation of the stressed-strained state of a roadbed structure was performed by a finite element method for different movement conditions and different regions based on climatic conditions. According to the simulation results, it has been determined that when changing the module of elasticity of an asphalt-concrete layer in the range from 400 MPa to 5,000 MPa, the tangential stresses in the contact between an asphalt-concrete and a cement-concrete layer change linearly. When the horizontal force changes in the range from 5 kN to 45 kN, the tangential stresses in the contact between the asphalt-concrete and cement-concrete layers also change linearly. The result of the simulation of the stressed-strained state has established the following:

– an increase in the thickness of an asphalt-concrete layer from 2 cm to 10 cm leads to a decrease in the tangent stresses τ_{xz} in the layer contacts;

– the tangent stresses τ_{xz} increase significantly when the value of the horizontal force increases.

2. The strength parameters of an asphalt-concrete layer and the tarring layer significantly depend on temperature; therefore, in order to devise practical recommendations, different groups have been taken into consideration based on the temperature intervals in the heating of an asphalt-concrete road surface:

– group I, heated to 53 °C (regions A_1, A_2, A_3 for the operational condition of an asphalt-concrete road surface);

– group II, heated to 55 °C (regions A_4, A_6 for the operational condition of an asphalt-concrete road surface);

– group III, heated to 57 °C (regions A_5, A_7 for the operational condition of an asphalt-concrete road surface).

Based on the analysis of our calculations, the minimum permissible thicknesses of an asphalt-concrete layer on a rigid base have been established, which must be provided for during the design, in order to ensure reliable adhesion between the layer contacts. We have devised recommendations for the use of spray tarring, surfacing waterproofing, and bitumen emulsion under conditions of movement along the road, along curves in the plan, and along the longitudinal profile, as well as along sections with emergency braking.

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