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A. F. Zubkov [1], L. S. Zarapina [2], K. A. Andrianov [3]

INFLUENCE OF THE LOAD ON THE MODULUS OF ELASTICITY OF THE ASPHALT GRANULATE LAYER DURING THE RESTORATION SURFACE OF THE ROAD CONSTRUCTION PAVEMENT

Tambov State Technical University [1, 2, 3]
Russia, Tambov

[1] *D. Sc. in Engineering, Prof. of the Dept.* of *Urban Construction and Highways,*
e-mail: afzubkov2013@yandex.ru
[2] *PhD student of the Dept. of Urban Construction and Highways,e-mail: lyubov.guseva.2012@bk.ru*
[3] *Ph.D. in Engineering, Assoc. Prof., Head of the Dept.* of *Urban Construction and Highways,*
e-mail: konst-68@yandex.ru

Statement of the problem. The effect of the size of fractions, layer thickness during compaction and the percentage of bitumen emulsion of asphalt granulate obtained during the destruction of an old non-rigid pavement by cold milling on the elastic modulus of the pavement is investigated.
Results. It has been experimentally proven that taking into account the size of the fractions, the introduction of a bitumen emulsion into the mixture of asphalt granulate has a different effect on the strength characteristics of the asphalt granular concrete mixture. The greatest effect when the emulsion is introduced into asphalt granulate is achieved at 2 %. For a mixture of a fraction of 5—20 mm, an increase in the bitumen emulsion from 2 to 4 % has no significant effect on the strength characteristics. For an asphalt-granular concrete mixture with fractions of 20—40 mm, with an increase in the emulsion content above 2 %, a decrease in the strength characteristics of the pavement layer occurs, which is explained by the structure of the compacted layer.
Conclusion. Dependences for determining the modulus of elasticity of an asphalt granulate layer are presented taking into account its thickness, particle size and the percentage of bitumen emulsion in the mixture.

Keywords: asphalt granulate, asphalt-granular concrete mixture, layer thickness, fraction, bitumen emulsion, modulus of elasticity, stress.

Introduction. Currently due to the increase in traffic intensity and axle load, more rigid requirements are imposed on the choice of materials for road structures during the construction, reconstruction and overhaul of highways. Road construction is characterized by significant volumes and cost of the materials used. Reducing the cost of building road pavement for highways is possible due to the reuse of the material obtained by cold milling of the old pavement. Construction practice has shown that the resulting waste from the destruction of old non-rigid coatings during major repairs and reconstruction of highways is widely used both abroad and in our country.

The use of waste from cold milling is possible, provided that the resulting material in terms of strength characteristics meets the requirements of regulatory documents. The strength of the pavement layer under load is characterized by the modulus of elasticity, the value of which depends on the category of the road, the properties of the material used, the load and its thickness [1—7].

1. Experimental research. The influence of the elastic modulus on the stress of the asphalt granulate layer, taking into account the particle size of the fraction, the layer thickness and the emulsion content in the mixture, was carried out under laboratory conditions using a PG-500 press. The deformation of the material layer was measured with a dial gauge with an accuracy of 0.01 mm when the material layer was loaded at a given stress value with a stamp with an area of 4.00 cm^2 [2, 8, 9].

To clarify the effect of the thickness of the pavement layer, the size of the asphalt granulate particles, the emulsion content in the asphalt-granular concrete mixture and the load on the modulus of elasticity of the layer, studies of the asphalt-granular concrete mixture of fractions 5—20 mm and 20—40 mm were carried out. The research data can be used both for pavement layers and for layer splitting. Fig. 1 shows the dependences of the modulus of elasticity of a layer of asphalt granulate under the action of a load, taking into account its thickness and size of the fraction.

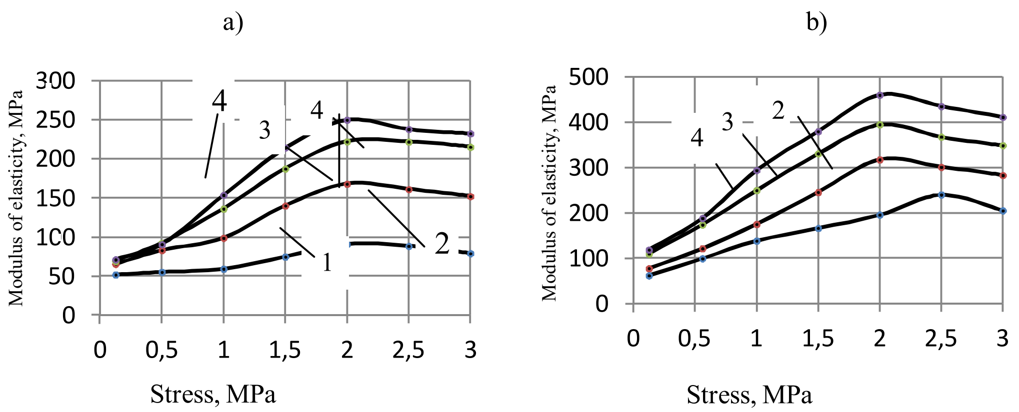


Fig. 1. Dependence of the modulus of elasticity on stress: a is fraction 5—20 mm; b is 20—40 mm: 1 is layer thickness 0.05 m; 2 is 0.10 m; 3 is 0.15 m; 4 is 0.2 m

Based on the data in Fig. 1, it can be seen that regardless of the size of the asphalt granulate fractions and the thickness of its layer during paving, there is a general pattern of the effect of stress on the modulus of elasticity. The numerical value of the modulus of elasticity of a layer of asphalt granulate from loading at different thicknesses is presented in Table 1.

Table 1 accepted σ as stress, MPa.

Table 1

Dependence of the modulus of elasticity
of a layer of asphalt granulate on stress at different thicknesses

Fraction, mm	Modulus of elasticity, MPa	Correlation coefficient
5—20	$E_{y0.05} = -8.86\sigma^3 + 35.93\sigma^2 - 20.1\sigma + 55.01$	0.98
	$E_{y0.10} = -13.18\sigma^3 + 46.02\sigma^2 + 8.99\sigma + 64.8$	0.98
	$E_{y0.15} = -13.47\sigma^3 + 39.63\sigma^2 + 53.07\sigma + 60.27$	0.99
	$E_{y0.20} = -15.03\sigma^3 + 38.69\sigma^2 + 76.39\sigma + 55.33$	0.98
20—40	$E_{y0.05} = -12.19\sigma^3 + 37.62\sigma^2 + 47.45\sigma + 59.41$	0.97
	$E_{y0.10} = -25.53\sigma^3 + 81.64\sigma^2 + 54.52\sigma + 69.36$	0.99
	$E_{y0.15} = -19.7\sigma^3 + 38.21\sigma^2 + 147.48\sigma + 88$	0.99
	$E_{y0.20} = -23.68\sigma^3 + 47.22\sigma^2 + 175.79\sigma + 91.07$	0.99

2. Analysis of the results of experimental research. To establish the general dependence of the effect of stress on the obtained modulus of elasticity of the layer, the data in Fig. 1 is presented in relative values, taking (conditionally) the modulus of elasticity at a stress of 1.0 MPa for each layer as a unit. As an example, Table 2 shows the values of the modulus of elasticity in relative values for each layer of the fraction 20—40 mm.

Table 2

Values of the modulus of elasticity of the layer of asphalt granulate from stress

Stress, MPa	Layer thickness, m				Σn/n
	0.05	0.10	0.15	0.20	
0.125	0.45	0.45	0.44	0.4	0.43
0.56	0.72	0.7	0.70	0.64	0.69
1.00	1.00	1.00	1.00	1.00	1.00
1.50	1.2	1.40	1.32	1.29	1.30
2.00	1.41	1.81	1.58	1.56	1.59
2.50	1.73	1.71	1.47	1.48	1.59
3.00	1.48	1.61	1.40	1.40	1.47

Fig. 2 shows the general dependences of the modulus of elasticity of a layer of asphalt granulate in relative values for fractions of 5—20 mm and 20—40 mm with different thicknesses.

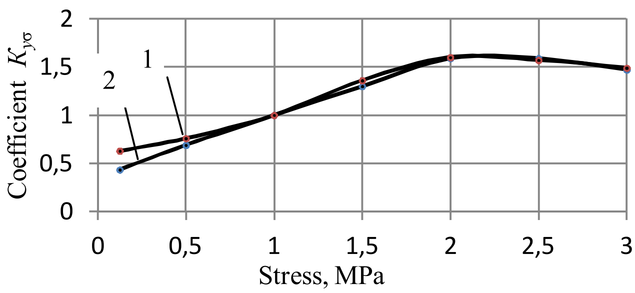


Fig. 2. General dependence of the modulus of elasticity of a layer of asphalt granulate:
1 fraction 20—40 mm; 2 — 5—20 mm

The numerical value of the coefficient $K_{y\sigma}$ under the action of the load is given by the dependence, $K_{y\sigma}$ is the dimensionless quantity:

— fraction 20—40 mm: $K_{y\sigma 20-40} = -0.087\sigma^3 + 0.214\sigma^2 + 0.508\sigma + 0.375$, (1)

— fraction 5—20 mm: $K_{y\sigma 5-20} = -0.115\sigma^3 + 0.384\sigma^2 + 0.174\sigma + 0.594$, (2)

where σ is stress, MPa. The correlation coefficient of the equation is 0.99

To clarify the effect of the thickness of the asphalt granulate layer on its modulus of elasticity, the data in Fig. 1 is presented in relative values, taking the values of the elastic modulus of each layer at a thickness of 0.1 m per unit. Let us designate this value as the coefficient of influence of the layer thickness on the modulus of elasticity (K_{yh}). The effect of the layer thickness on the value of the coefficient K_{yh} is shown in Fig. 3

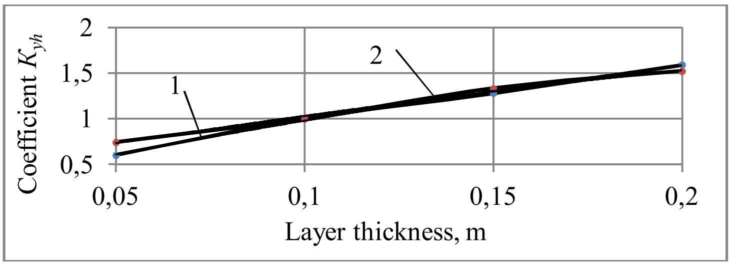


Fig. 3. Dependence of the coefficient K_{yh} on the layer thickness:
1 — fraction 5—20 mm; 2 — 20—40 mm

The numerical value of the coefficients K_{yh} is given by the dependence, K_{yh} is a dimensionless quantity:

— fraction 5—20 mm: $K_{yh5-20} = -9h^2 + 8.75h + 0.19$, (3)

— fraction 20—40 mm: $K_{yh20-40} = -6.9h^2 + 7.06h + 0.39$, (4)

where h is the layer thickness, m. The correlation coefficient is 0.99.

Taking into account the obtained values of the coefficients, the dependences for determining the modulus of elasticity of the layer of asphalt granulate have the following form, MPa:

— fraction 20—40 mm: $E_{y20-40} = 175.4 K_{y\sigma} K_{yh}$, (5)

— fraction 5—20 mm: $E_{y5-20} = 99 K_{y\sigma} K_{yh}$. (6)

The results of calculating the ultimate strength of a layer of asphalt granulate under the action of a load, taking into account its thickness, showed that the relative error of the results obtained is from 5 to 10 %.

When constructing road pavements, asphalt-granulo-concrete mixtures are used, obtained by adding a binder material to asphalt granulate obtained after cold milling of an old non-rigid type pavement. The introduction of a binder into the asphalt granulate restores the properties of the mixture, which provides adhesion between its particles during compaction. Liquid bitumen, bitumen emulsions, lime, cement and combined additives in the form of a combination of different components are used as a binder. Depending on the binding materials, the mixtures have not only different physical and mechanical characteristics, but also the rate of structure formation, which makes it possible to use them when arranging layers on all categories of highways. When repairing and reconstructing roads of I—III technical categories, asphalt-granuloconcrete mixtures are used for the construction of foundations and lower layers of the pavement, and on roads of IV—V [4] categories it is allowed for use for the arrangement of the upper layers of the pavement with subsequent surface treatment of the pavement (Fig. 4).

Fig. 4. Construction of road pavements using asphalt-granular concrete mixtures in the Tambov region (photo by the authors)

The practice of using asphalt-granulo-concrete mixtures in road construction has shown that bitumen emulsions are widely used as a binder. The use of a bitumen emulsion, in contrast to other binders, is less costly to ensure the required characteristics of road pavements. It has been experimentally established that after the destruction of the old asphalt concrete pavement, the asphalt granulate contains from two to four percent of bitumen. Therefore, when an emulsion is introduced into a mixture, it does not only provide adhesion between particles, but also affects its characteristics.

To establish the influence of different factors (layer thickness, percentage of emulsion and load) on the deformation value, layers with a thickness of 0.05 m were formed; 0.1 m and 0.15 m with different percentage of emulsion and actual load. The experimental research methodology was similar to the testing of asphalt granulate. Based on the results of testing the asphalt-granulo-concrete mixture, the characteristics of the pavement layer were determined ensuring its reliability and durability. The modulus of elasticity is taken as a characteristic. It was found that the modulus of elasticity of the road pavement depends on the stress, layer thickness, traffic intensity, axle load and road category [1]. For a pavement layer made of asphalt-granular concrete mixture, the modulus of elasticity can be represented as a function:

$$E_y = f(\sigma; h; E), \text{ MPa} \tag{7}$$

where σ is the stress in the zone of contact of the tire with the surface of the layer, MPa; h is the layer thickness, m; E is the content of the emulsion in the mixture, %.

Based on the results of measuring the deformation of a layer of an asphalt-granular concrete mixture under the action of a load, the dependences of the elastic modulus of the layer at different stress values are established as shown in Fig. 5 and 6.

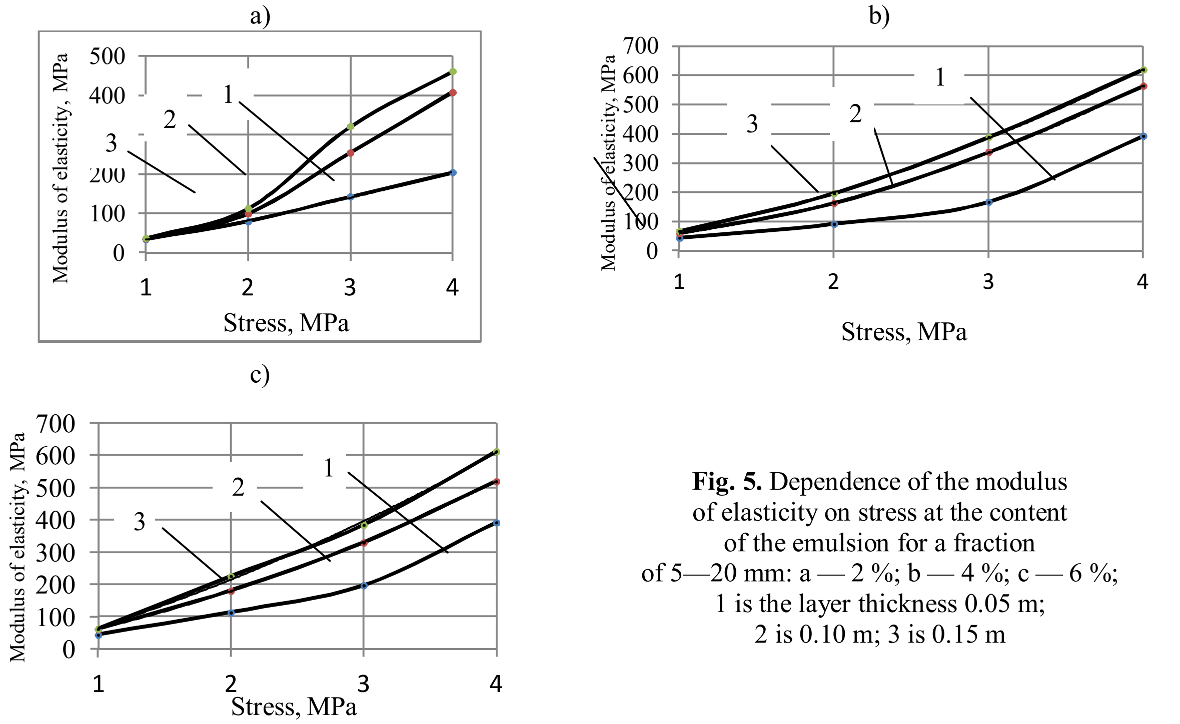
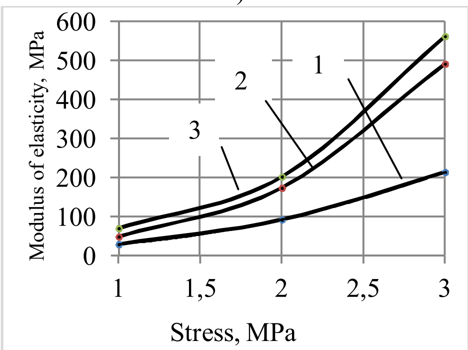


Fig. 5. Dependence of the modulus of elasticity on stress at the content of the emulsion for a fraction of 5—20 mm: a — 2 %; b — 4 %; c — 6 %; 1 is the layer thickness 0.05 m; 2 is 0.10 m; 3 is 0.15 m

The numerical values of the modulus of elasticity versus stress are presented in Table 3 and 4. In table 3.4, σ is taken — stress, MPa. The correlation coefficient of the equations is 0.99—1.0. To establish the general dependence of the elastic modulus on stress, the data in Fig. 5.6 is presented in relative values, taking the elastic modulus at a stress of 1.0 MPa per unit. Let us denote this value by the coefficient K_σ, which characterizes the effect of stress on the elastic modulus of the layer. Table 5.6 shows the dependences of the K_σ coefficients on the stress for fractions 5—20 mm and 20—40 mm.

In Table 5, 6 it is accepted σ is stress, MPa. The correlation coefficient of the equations is 0.99—1.0.

a)



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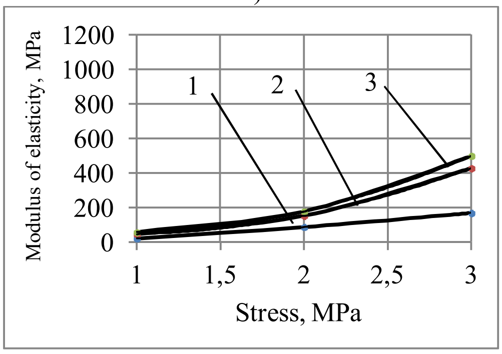

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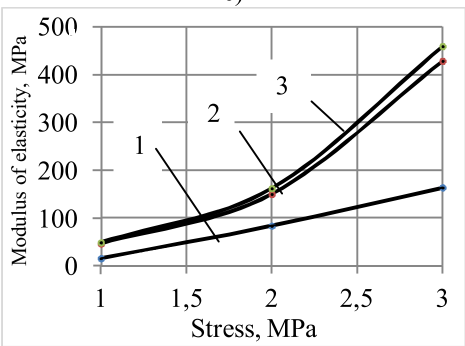

Fig. 6. Dependence of the modulus of elasticity on stress at the content of the emulsion for the fraction 20—40 mm: a is 2 %; b is 4 %; c is 6 %; 1 is layer thickness 0.05 m; 2 is 0.10 m; 3 is 0.15 m

Table 3

Dependencies for calculating the modulus of elasticity of a layer from an asphalt-granular concrete mixture with a fraction of 5—20 mm (MPa)

Thickness layer, m	Emulsion content, %		
	2	4	6
0.05	$E_y = 3.97\sigma^2 + 37.51\sigma - 8.5$	$E_y = 44.51\sigma^2 - 110.4\sigma + 115.4$	$E_y = 31.35\sigma^2 - 43.99\sigma + 61.72$
0.10	$E_y = 22.6\sigma^2 + 14.36\sigma - 6.15$	$E_y = 30.89\sigma^2 + 14.05\sigma + 13.94$	$E_y = 17.84\sigma^2 + 63.07\sigma - 18.72$
0.15	$E_y = 16.11\sigma^2 + 67.84\sigma - 57.4$	$E_y = 25.37\sigma^2 + 51.81\sigma - 17.44$	$E_y = 16.08\sigma^2 + 100.52\sigma - 50.71$

Table 4

Dependencies for calculating the modulus of elasticity of a layer from an asphalt-granulo-concrete mixture with a fraction of 20—40 mm (MPa)

Thickness layer, m	Emulsion content, %		
	2	4	6
0.05	$E_y = 29.26\sigma^2 - 24.59\sigma + 24.73$	$E_y = 7.73\sigma^2 + 42.53\sigma - 26.68$	$E_y = 5.97\sigma^2 + 50.13\sigma - 40.09$
0.10	$E_y = 96.39\sigma^2 - 164.\sigma + 116.4$	$E_y = 115.86\sigma^2 - 241.3\sigma + 173.1$	$E_y = 87.17\sigma^2 - 157.65\sigma + 116.99$
0.15	$E_y = 113.76\sigma^2 - 209\sigma + 165.66$	$E_y = 99.89\sigma^2 - 179.1\sigma + 138.26$	$E_y = 92.02\sigma^2 - 163.08\sigma + 120.24$

Based on the above dependences of K_σ on stress, it can be seen that they are characterized by a general pattern, which makes it possible to establish the general dependence of the coefficient K_σ on stress for fractions with equal emulsion content in the mixture regardless of the layer thickness. The numerical values of the generalized dependencies are determined by the formulas presented in Table 7, the form of the dependencies is shown in Fig. 7.

Table 5

Values of the coefficient K_σ for asphalt-granular concrete mixture of fraction 5—20 mm at different emulsion content

Thickness layer, m	Emulsion content, %		
	2	4	6
0.05	$K_\sigma = 0.27\sigma^2 + 0.52\sigma + 0.21$	$K_\sigma = 0.33\sigma^2 + 0.12\sigma + 0.56$	$K_\sigma = 0.17\sigma^2 + 1.05\sigma - 0.22$
0.10	$K_\sigma = 1.3\sigma^2 - 2.1\sigma + 1.8$	$K_\sigma = 0.46\sigma^2 + 0.54\sigma + 0.01$	$K_\sigma = 0.25\sigma^2 + 1.17\sigma - 0.42$
0.15	$K_\sigma = 1.82\sigma^2 - 3.4\sigma + 1.58$	$K_\sigma = 0.46\sigma^2 + 0.54\sigma + 0.01$	$K_\sigma = -0.03\sigma^2 + 2.71 - 1.68$

Table 6

Values of the coefficient K_σ for asphalt-granular concrete mixture of fraction 20—40 mm with different emulsion content

Thickness layer, m	Emulsion content, %		
	2	4	6
0.05	$K_\sigma = 3.06\sigma^2 - 7.7\sigma + 5.64$	$K_\sigma = 4.29\sigma^2 - 9.72\sigma + 6.43$	$K_\sigma = 4.9\sigma^2 - 8.7\sigma + 4.8$
0.10	$K_\sigma = 0.54\sigma^2 + 0.51\sigma - 0.05$	$K_\sigma = 2.01\sigma^2 - 3.89\sigma + 2.88$	$K_\sigma = 1.13\sigma^2 - 1.17\sigma + 1.04$
0.15	$K_\sigma = 1.27\sigma^2 2.43\sigma + 2.16$	$K_\sigma = 0.87\sigma^2 - 1.77\sigma + 1.99$	$K_\sigma = \sigma^2 - 1.5\sigma + 1.5$

Table 7

Generalized dependencies for calculating the coefficient $K_{\sigma gen}$

Fraction, mm	Emulsion content, %		
	2	4	6
5—20	$K_{\sigma gen} = 1.51\sigma^2 - 3.03\sigma + 2.52$	$K_{\sigma gen} = -0.265\sigma^2 4.37\sigma - 3.11$	$K_{\sigma gen} = 0.27\sigma^2 + 3.87\sigma - 3.14$
20—40	$K_{\sigma gen} = 1.63\sigma^2 - 3.23\sigma + 2.6$	$K_{\sigma gen} = 2.01\sigma^2 - 3.89\sigma + 2.88$	$K_{\sigma gen} = 2.35\sigma^2 - 3.85\sigma + 2.45$

In Table 7, σ is taken as stress, MPa. The correlation coefficient of the equations is 0.99—1.0.

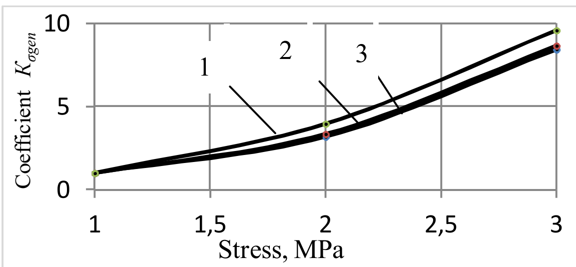

Fig. 7. Generalized dependence of the coefficient $K_{\sigma gen}$ on stress: 1 is emulsion content 2 %; 2—4 %; 3—6 %

The modulus of elasticity of the layer depends on its thickness, which can be seen from the data presented in Fig. 5 and 6. To clarify the effect of the layer thickness on the elastic modulus, we take (conditionally) in relative values the elastic modulus at a layer thickness of 0.05 m per unit for all the layers regardless of the emulsion content (Fig. 8).

a) b)

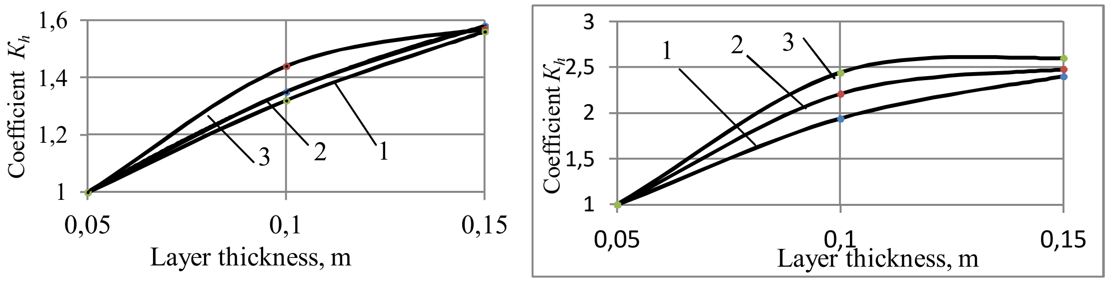

Fig. 8. The influence of the layer thickness on its modulus of elasticity in relative values:
a — fraction 5—20 mm; b — fraction 20—40 mm;
1 — emulsion content 2 %; 2—4 %; 3—6 %

The numerical values of the K_h coefficients taking into account the content of the emulsion in the mixture are determined by the formulas presented in Table 8. According to the results presented in Table 8, it can be seen that the content of the emulsion in the mixture affects the modulus of elasticity. In order to clarify the effect of the emulsion content in the mixture on the modulus of elasticity of the layer, the data in Table 8 is presented in relative values, assuming for a layer of 0.05 m the modulus of elasticity at all stresses per unit (Fig. 9).

Table 8

Generalized dependencies for calculating the coefficient K_h

Fraction, mm	Emulsion content, %		
	2	4	6
5—20	$K_h = -26h^2 + 10.9h + 0.52$	$K_h = -62h^2 + 18.1h + 0.25$	$K_h = -16h^2 + 8.8h + 0.6$
20—40	$K_h = -96h^2 + 33.2h - 0.42$	$K_h = -188h^2 + 52.4h - 1.15$	$K_h = -256h^2 + 67.2h - 0.42$

a) b)

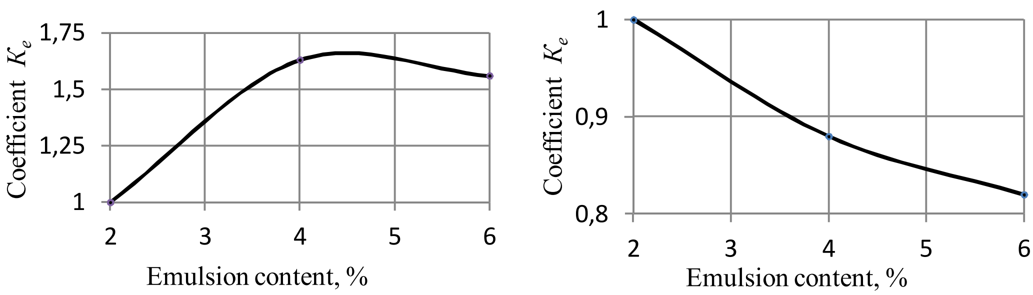

Fig. 9. Influence of the content of the emulsion in the mixture on its modulus of elasticity:
a is fraction 5—20 mm; b is 20—40mm

The numerical value of the coefficients $K_{\%e}$ is determined by the formulas, $K_{\%e}$ is a dimensionless quantity:

— fraction 5-20 mm: $K_{\%e} = -0.074E^2 + 0.717E - 0.14$, (8)

— fraction 20-40 mm: $K_{\%e} = 0.0075E^2 - 0.105E + 1.18$, (9)

where E is the percentage of the emulsion in the mixture. The correlation coefficient is 0.9

The modulus of elasticity of a layer of asphalt granulate taking into account the action of the load, the layer thickness and the percentage of emulsion is given by the formula:

$$E_y = 34K_{\%e}K_hK_{\sigma gen}\text{, MPa.} \quad (10)$$

Conclusion

1. The use of asphalt granulate and asphalt granule concrete mixtures for road construction allows one to reduce the need for crushed stone, which affects the cost of work.

2. When the material is compacted after cold milling of old non-rigid pavements, the required strength of the layers of the road structure is ensured both without the addition of an emulsion and with one.

3. The use of the emulsion in the preparation of the asphalt-granulo-concrete mixture increases the ultimate strength of the layer from 30 to 80 %, depending on the granulometric composition of the mixture.

4. The maximum increase in layer strength is achieved by adding 2 % emulsion to the asphalt granulate. As the amount of emulsion continues increasing, a decrease in the ultimate strength is observed regardless of the composition of the mixture. The greatest influence on the strength characteristics of the asphalt-assisted concrete mixture is exposed to the fraction of 20—40 mm, which is accounted for by the structure of the layer.

5. A generalized dependence for determining the modulus of elasticity of a layer of asphalt granulate taking into account the action of the load, the thickness of the layer and the percentage of the emulsion has been obtained.

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