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INFLUENCE OF THE PROPERTIES OF THE MATERIAL OBTAINED BY COLD MILLING OF NON-RIGID PAVEMENTS ON THE DEFORMATION OF THE LAYER DURING THE CONSTRUCTION OF THE PAVEMENT

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Statement n of the problem. Establish the effect of the size of material fractions, thickness and percentage of bitumen emulsion obtained by milling non-rigid pavements on the deformation of the layer during pavement construction.
Results. It has been experimentally proven that there is a correlation between the density, strength and deformation of the layer under the action of a sealing load. The material obtained by cold milling of old non-rigid coatings has its own characteristics that must be taken into account when using it. The introduction of a binder into asphalt granulate affects not only the properties of the asphalt-granular concrete mixture, but also the formation of the structure of the pavement layer.
Conclusion. Dependencies for calculating the deformation of the pavement layer have been obtained, which make it possible to predict the strength characteristics of the layer by deformation at different sizes of material fractions, layer thickness and percentage of bitumen emulsion in the mixture under the existing load during the compaction process.

Keywords: asphalt granulate, asphalt-granular concrete mixture, fraction size, deformation, layer thickness, stress, bitumen emulsion.

Introduction. Under the influence of the climatic conditions of operation of the road and the axial load of vehicles, changes occur in the properties of asphalt concrete pavements associated with the applied binders. When the bitumen film interacts with air, oxidation and polymerization processes occur, which affect the deformation properties of bitumen films and the adhesion forces of particles of mineral materials of asphalt concrete.

This leads to a decrease in the strength characteristics of the coating, the formation of defects which require timely repair. At the same time, the mineral components of asphalt concrete do not change their characteristics during the operation of the highway, which allows them to be reused during reconstruction and repair work [1, 2].

According to the results of testing of asphalt granulate, it was found that the content of bitumen in the particles of destroyed asphalt concrete pavement is in the range from 2 to 4 %, which is a full-fledged building material, the use of which is technically feasible and economically justified [3—7]. The experience of foreign countries and the practice of road organizations in Russia has shown that the resulting waste from the destruction of asphalt concrete pavements can reduce the need for materials while simultaneously solving the issue of recycling the resulting waste. The most effective process of destruction of the asphalt concrete pavement is carried out by means of the method of cold milling with the use of road mills. As a result of milling the road surface, a material is obtained in the form of granules with a surface bitumen film, the dimensions of which depend on the type of mixture and the operating modes of the cold mill.

Taking into account the operation time of the road, the bitumen film on the surface of the particles of the mineral material acquires hardness, which affects the coefficient of friction between the particles and contributes to a higher rigidity of the layer under the action of an external load, which must be taken into account when choosing compaction machines. The resulting material (asphalt granulate), in compliance with the strength requirements of the regulatory documents ODM 218.2.022-2012, ODM 218.2.017-2011 and the order of the Federal Road Transport Agency No. OC-568-p.

By adding a binder (emulsion, liquid bitumen, lime, cement) to the asphalt granulate, an asphalt-granulo-concrete mixture is obtained which is used in the construction of layers of pavement. The use of a binder makes it possible to increase not only the strength of the material used, but also the rate of structure formation, which makes it possible to effectively use them in the construction of road pavements on all categories of highways. When repairing and reconstructing roads of I—III technical categories, mixtures are used for the construction of foundations and lower layers of the pavement, and on roads of IV—V categories it is allowed to use them for the arrangement of the upper layers of the pavement with subsequent surface treatment. Depending on the size of the particles, the mixtures are characterized by a maximum granule size of 5; twenty; 40 and 80 (70) mm. When constructing road pavements, the content of granules larger than 50 mm should not exceed 5 % by weight.

Depending on the design parameters of the road, the layer thickness during laying has different values, which affects the strength characteristics of the layer. It has been established that the size of the granules of asphalt granulate, the thickness of the layer during laying and the content of the emulsion in the asphalt granular concrete mixture affect the properties of the laid layer, which must be taken into account when developing technological compaction processes.

In order to increase the efficiency of the compaction process and the quality of work when arranging layers with the use of asphalt granulate and asphalt-granular concrete mixtures, it is necessary to establish the regularities of the influence of the size of the mixture fractions as well as the layer thickness during laying and the emulsion content on the characteristics of the layer. The influence of the load on the amount of deformation of the laid layer and thereby on its characteristics is carried out on the basis of experimental studies. So, in STO NOSTROY 2.25.35-2012 and experimental studies [8-10] it is proved that there are correlation dependences between deformation under load and physical and mechanical characteristics of the compacted layer. Under the action of the load, the value of the total deformation (λ_{tot}) of the material layer is given by the expression:

$$\lambda_{tot} = \lambda_{el} + \lambda_{per}, \text{ mm}, \quad (1)$$

where λ_{el} is the elastic deformation, mm; λ_{per} is the permanent deformation, mm.

1. Experimental research. The influence of the load on the deformation of the layer of asphalt granulate and asphalt granulo-concrete mixtures taking into account the size of the particles of the fraction, the thickness of the layer and the content of the emulsion in the mixture was carried out in laboratory conditions using a PG-500 press. The deformation of the material layer was measured with a dial indicator with an accuracy of 0.01 mm when the material layer was loaded at a given stress value with a punch with an area of 4.00 cm^2.

The asphalt granulate obtained as a result of cold milling of the old asphalt concrete pavement was divided into fractions of 5—20 and 20—40 mm. Laying was carried out in layers with a thickness of 0.05; 0.10; 0.15 and 0.20 m. When testing the asphalt-granulo-concrete mixture with the addition of the EBK-3 emulsion, the layer thickness was taken as 0.05; 0.10 and 0.15 m. To clarify the effect of the emulsion content on the characteristics of the layer of the asphalt-granulo-concrete mixture, the asphalt granulate was mixed with the emulsion at different percentages.

After laying and preliminary compaction of the layer, a stamp was placed on the surface. The upper press plate was installed above the level of the surface of the stamp by 1.5—2.0 mm. To measure the deformation, the indicator attached to the stand was placed in such a way that the movable part of its leg touched the top plate of the press. After that, the load was transferred to the material layer through the stamp. The movement of the stamp was measured at a given voltage value, i.e. complete deformation of the material layer. After removing the load on the punch, the elastic deformation was measured with the subsequent repetition of the load cycle. The result was taken as a value representing the arithmetic mean of tests from three samples, rounded to the second decimal place. The discrepancy between the obtained results did not exceed 10 %.

2. Analysis of the results of experimental research. Table 1, 2 shows the results of measuring the deformations of the layer of asphalt granulate fractions with sizes of 5—20 and 20—40 mm under the action of a load.

Table 1

Results of measuring the deformations of the layer of the fraction 5-20 mm

σ, MPa	Thickness 0.05 m			Thickness 0.10 m			Thickness 0.15 m			Thickness 0.20 m		
	λ_{tot}	λ_{per}	λ_{el}	λ_{tot}	$\lambda_{осm}$	λ_{tot}	λ_{per}	λ_{el}	λ_{tot}	$\lambda_{пол}$	λ_{tot}	λ_{per}
0.125	6.93	6.81	0.12	7.0	6.81	0.19	11.59	11.3	0.29	13.1	12.9	0.40
0.5	2.47	2.10	0.45	3.65	3.05	0.60	3.35	2.54	0.81	5.19	4.08	1.10
1	3.01	2.17	0.84	4.98	3.97	1.01	5.81	4.71	1.1	6.80	4.54	1.30
1.5	3.45	2.45	1.0	3.31	2.24	1.07	3.32	2.12	1.2	3.26	2.16	1.10
2	2.51	1.41	1.1	2.77	1.58	1.19	3.78	2.48	1.3	1.81	0.26	1.55
2.5	3.64	2.23	1.41	3.13	1.58	1.55	3.13	1.64	1.69	4.43	2.33	2.10
3.0	5.71	3.82	1.89	5.58	3.61	1.97	6.12	4.23	2.09	6.95	4.37	2.58

Table 2

Results of measuring the deformations of the layer of the fraction 20-40 mm

σ, MPa	Thickness 0,05 m			Thickness 0,10 m			Thickness 0,15 m			Thickness 0,20 m		
	λ_{tot}	λ_{per}	λ_{el}	λ_{tot}	$\lambda_{осm}$	λ_{tot}	λ_{per}	λ_{el}	λ_{tot}	$\lambda_{пол}$	λ_{tot}	λ_{per}
0.125	4.07	3.97	0.1	5.24	5.08	0.16	7.17	7	0.17	8.88	8.67	0.21
0.5	2.17	1.92	0.25	1.87	1.46	0.41	3.13	2.7	0.43	3.57	3.04	0.53
1	2.36	2	0.36	5.45	4.88	0.57	5.82	5.22	0.60	4.97	4.29	0.68
1.5	0.7	0.25	0.45	0.81	0.2	0.61	0.86	0.18	0.68	1.65	0.86	0.79
2	1.3	0.79	0.51	0.97	0.34	0.63	0.95	0.19	0.76	1.73	0.86	0.87
2.5	2.78	2.26	0.52	2.99	2.16	0.83	2.99	1.97	1.02	3.71	2.56	1.15
3.0	3.44	2.71	0.73	4.51	3.45	1.06	5.16	3.87	1.29	6.45	4.99	1.46

The obtained experimental data on the formation of deformations (complete, elastic) under the action of a load on the layer of asphalt granulate make it possible to establish the regularities of changes in the characteristics of the layer and the properties of the material during the compaction process.

The value of the residual deformation of the asphalt granulate layer under the action of the load taking into account the size of the fraction and the layer thickness during paving is shown in Fig. 1.

Based on the data in Fig. 1, it can be seen that the development of deformation in the compacted layer depends on its thickness and size of the fraction. When forming a layer of 5—20 mm fraction, the development of permanent deformation depends on the stress in the zone of contact with the layer surface. At a stress of up to 1.0 MPa, there is a direct relationship between the effective stress and deformation. As stress increases, the intensity of the growth of the layer deformation decreases, which is accounted for by the formation of the layer structure regardless of its thickness during laying. When a layer of 20—40 mm fraction is arranged, the nature of deformation development under the action of a load is different. This difference in the development of layer deformation is explained by the formation of the layer structure. With an increase in the load to 1.0 MPa, the development of deformation in the layer is proportional to the stress in the zone of contact of the stamp with the surface of the layer. As voltage continues increasing, contacts arise between the particles of asphalt granulate, which contributes to an increase in the bearing capacity of the layer to load, which is characteristic of the frame structure. As stress continues increasing, so does deformation of the layer, which indicates a growth in the density of the material due to the compaction process.

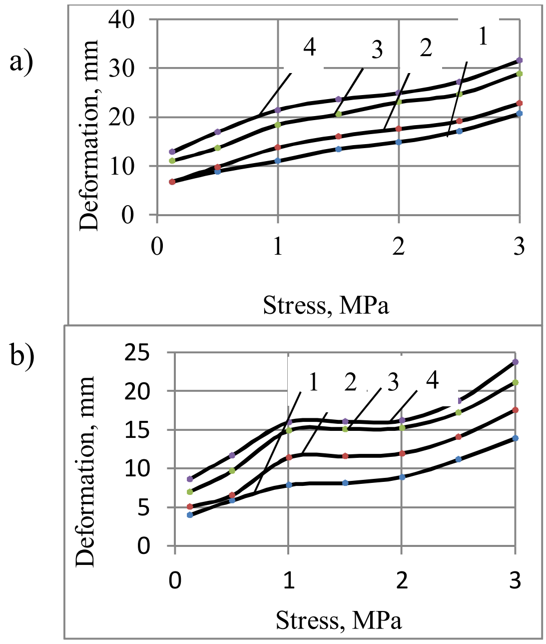

Fig. 1. Dependence of the total residual deformation of the layer on stress at different layer thicknesses and sizes of the asphalt granulate fraction:
a is 5—20 mm fraction;
b is fraction 20—40 mm;
1 is layer thickness 0.05 m;
2 is 0.10m; 3 is 0.15m; 4 is 0.2m

To establish the general regularity of the development of deformation in a layer under the action of a load, regardless of its thickness, let us present the dependences shown in Fig. 1 in relative values conventionally taking the deformation of each layer at a stress of 1.0 MPa per unit (Table 3). We take this value as the coefficient of stress influence on the deformation of the material layer (K_σ) as shown in Fig. 2.

The numerical value of the coefficient K_σ is given by the expression:

$$K_\sigma = 0.064\sigma^3 - 0.326\sigma^2 + 0.79\sigma + 0.468 \text{, dimensionless value,} \quad (2)$$

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

To clarify the effect of the layer thickness on its deformation, we represent the deformation of each layer at a thickness of 0.1 m per unit. Let us denote this value by the coefficient of influence of the layer thickness on deformation under the action of a load (K_h), see Fig. 3.

Table 3

Dependence of deformation on stress at different layer thicknesses (in relative values)

Stress, MPa	Layer thickness, m				
	0.05	0.10	0.05	0.20	0.05
0.125	0.614	0.49	0.605	0.599	0.577
0.50	0.804	0.71	0.74	0.789	0.761
1.0	1.0	1.0	1.0	1.0	1.0
1.5	1.22	1.162	1.15	1.0999	1.158
2.0	1.35	1.27	1.249	1.158	1.2575
2.5	1.55	1.39	1.337	1.267	1.387
3.0	1.89	1.65	1.566	1.47	1.645

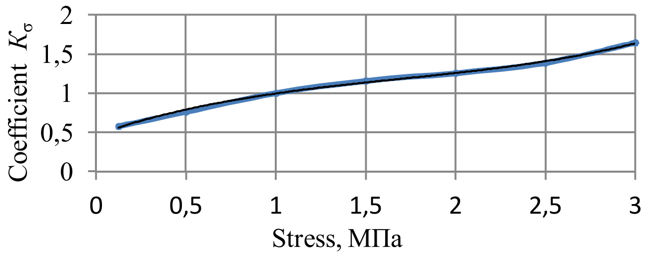

Fig. 2. Dependence of the coefficient K_σ on stress

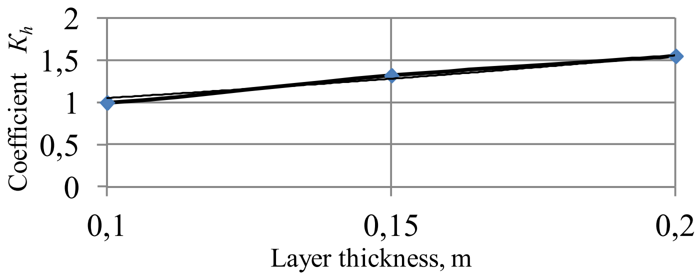

Fig. 3. Influence of layer thickness on coefficient K_h

The numerical value of K_h is given by the formula:

$$K_h = 0.71e^{3.92h}, \tag{3}$$

where h is the asphalt granulate layer thickness, m. The correlation coefficient is 0.98.

Taking into account the obtained data, the general dependence for calculating the deformation of a layer of asphalt granulate with a fraction of 5—20 mm regardless of its thickness and load can be given by the formula:

$$\lambda = 9.82K_\sigma e^{4.048h}, \text{ mm}. \tag{4}$$

Using the above methodology, a dependence was established for a layer of a fraction of 20—40 mm taking into account its thickness which takes the form:

$$\lambda = 7.31K_\sigma e^{4.42h}, \text{ mm}, \tag{5}$$

where h — layer thickness, m; K_σ is the coefficient of stress influence on the deformation of the material layer, dimensionless value, the numerical value is given by the formula:

$$K_\sigma = -0.23\sigma^2 + 0.8\sigma + 0.38, \tag{6}$$

where σ is stress, MPa. The correlation coefficient is 0.97.

It was found that the calculation error for the presented relationship is within 10—15 %.

As noted earlier, the practice of using asphalt-granulo-concrete mixtures has shown that when building road pavements and strengthening roadsides, mixtures with the use of bitumen emulsions are widely used. The use of bitumen emulsion, in contrast to other binders, is characterized by lower costs to ensure the required characteristics of road pavements.

Fig. 4 shows the effect of the emulsion content on the deformation of a 0.05 m thick layer at different emulsion contents.

Based on the data presented in Fig. 4, it can be seen that regardless of the composition and percentage of the emulsion in the mixture, the formation of deformation under the action of a load obeys a general pattern, at the same time the magnitude of deformation depends on the size of the asphalt granulate fractions. The amount of deformation of the layer depends on the content of the emulsion in the mixture, which is accounted for by a change in the thickness of the binder film on the surface of the asphalt granulate and a decrease in the friction forces between particles under the action of a load.

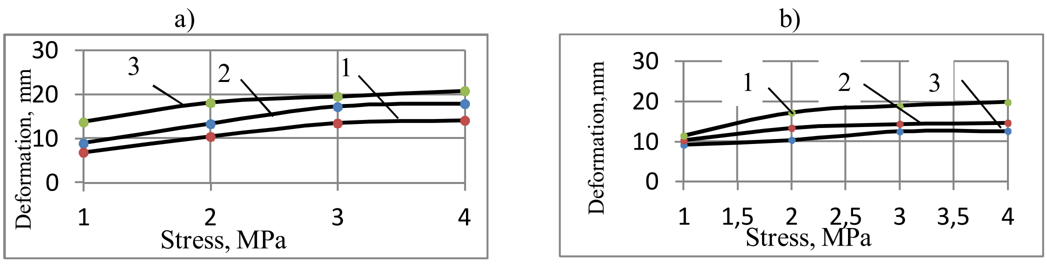

Fig. 4. Dependence of the deformation of a layer 0.05 m thick on stress at different emulsion contents: a is fraction 5—20 mm; b is fraction 20—40 mm; 1 is emulsion content 2 %; 2 is 4 %; 3 is 6 %

To establish the influence of various factors (layer thickness, percentage of emulsion and load) on the value of deformation, layers with a thickness of 0.05 were formed; 0.10 and 0.15 m with different percentage of emulsion and actual load. The experimental research methodology was similar to testing of asphalt granulate without emulsion. The results are shown in Table 4 and 5.

Table 4

Test results for asphalt-granulo-concrete mixtures of 5—20 mm fraction

Stress, MPa	Deformation, mm								
	Thickness 0.05 m			Thickness 0.10 m			Thickness 0.15 m		
	λ_{tot}	λ_{el}	λ_{per}	λ_{tot}	λ_{el}	λ_{per}	λ_{tot}	λ_{el}	λ_{per}
Emulsion content 2 %									
1.0	11.07	2.1	8.97	24.56	3.22	21.34	26.41	4.09	22.32
2.0	6.21	1.8	4.41	9.46	3.02	6.44	11.4	2.67	8.73
3.0	5.38	1.5	3.38	3.08	1.18	1.9	4.19	1.40	2.79
4.0	2.08	1.4	0.68	2.19	0.98	1.21	1.24	0.3	0.94

End of Table 4

Stress, MPa	Deformation, mm								
	Thickness 0.05 m			Thickness 0.10 m			Thickness 0.15 m		
	λ_{tot}	λ_{el}	λ_{per}	λ_{tot}	λ_{el}	λ_{per}	λ_{tot}	λ_{el}	λ_{per}
Emulsion content 4 %									
1.0	9.09	2.15	6.94	19.5	1.67	17.83	30.34	3.81	26.53
2.0	4.57	1.0	3.57	10.21	2.23	7.98	8.01	1.13	6.88
3.0	3.04	1.0	2.04	2.09	0.89	1.19	3.13	1.06	2.07
4.0	2.12	0.51	1.61	1.56	0.51	1.05	1.11	0.97	0.14
Emulsion content 6 %									
1.0	16.91	3.13	13.77	13.5	2.37	11.14	19.51	3.81	15.7
2.0	5.16	0.78	4.37	9.5	2.11	7.39	11.17	1.13	10.04
3.0	2.01	0.56	1.45	1.51	1.41	0.1	5.1	1.06	4.04
4.0	1.76	0.5	1.26	1.13	0.97	0.16	0.79	0.57	0.21

Table 5

Test results for asphalt-granulo-concrete mixtures of 20—40 mm fraction

Stress, MPa	Deformation, mm								
	Thickness 0.05 m			Thickness 0.10 m			Thickness 0.15 m		
	λ_{tot}	λ_{el}	λ_{per}	λ_{tot}	λ_{el}	λ_{per}	λ_{tot}	λ_{el}	λ_{per}
Emulsion content 2 %									
1	10.91	1.68	9.23	17.01	2.06	14.96	22.76	2.13	20.63
2	2.27	1.08	1.19	4.99	1.65	3.35	15.77	1.78	13.99
3	2.21	0.08	2.13	1.44	0.61	0.83	4.09	1.01	3.08
4	0.11	0	0.11	1.00	0.23	0.78	2.10	0.28	1.82
Emulsion content 4 %									
1	12.47	2.12	10.3	16.45	1.02	15.43	22.07	1.4	20.67
2	4.11	1.02	3.09	6.91	2.12	4.79	2.04	0.84	1.21
3	1.01	0.04	1.00	1.05	0.07	0.98	1.00	0.45	0.55
4	0.50	0.25	0.26	0.36	0.0	0.04	0.36	0.13	0.22
Emulsion content 6 %									
1	14.61	3.12	11.5	19.70	2.15	17.55	20.70	2.54	18.16
2	6.60	0.89	5.72	5.14	1.33	3.80	11.53	2.02	9.51
3	2.11	0.41	1.70	1.53	0.70	0.83	2.02	0.75	1.27
4	1.04	0.13	0.92	0.40	0.05	0.35	1.23	0.44	0.78

Based on the data presented in Table 4 and 5, the dependences of the deformation of the layer of asphalt-granulo-concrete mixtures of fraction 5—20 mm and 20—40 mm under the action of the load were obtained taking into account the percentage of emulsion in the mixture and the layer thickness (Fig. 5).

Based on the experimental data in Fig. 5, it can be seen that regardless of the layer thickness and the percentage of emulsion in the mixture, the dependences are characterized by a general regularity.

Dependences of the deformation of the layer of asphalt-granular concrete mixtures on the stress at different values of the layer thickness and emulsion content are presented in Table 6.

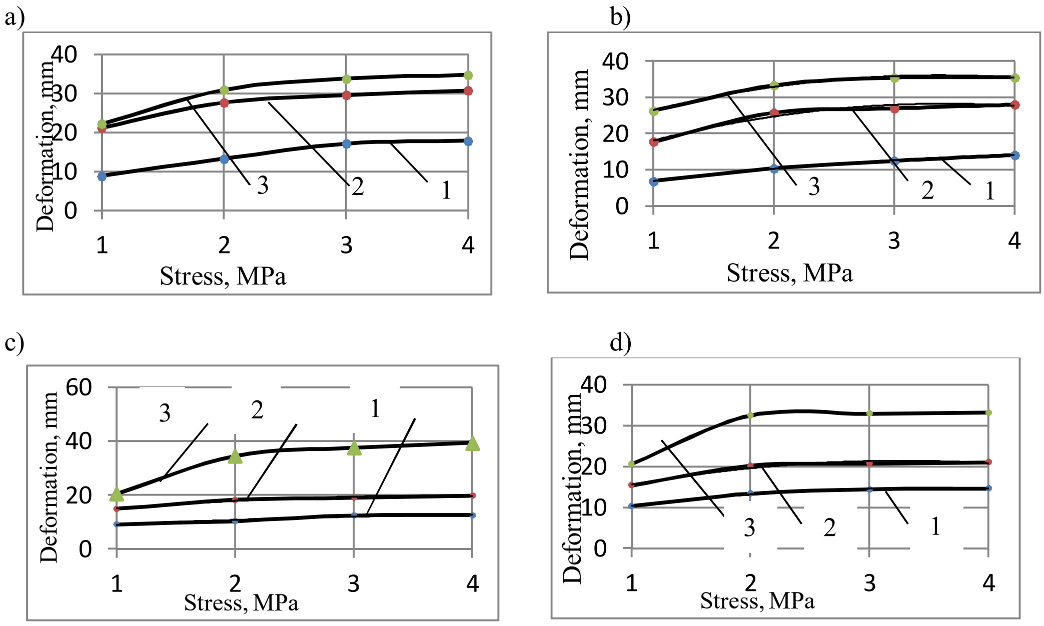

Fig. 5. Dependence of deformation on stress at different layer thickness and emulsion content:
a, b is fraction 5—20 mm; c, d is fraction 20—40 mm; a, c is emulsion content 2 %; b, d is 4 %;
1 is layer thickness 0.05 m; 2 is 0.10 m; 3 is 0.15m

To establish the general dependence of the effect of stress on the development of deformation of the layer of asphalt-granular concrete mixture, the data shown in Fig. 5 is presented in relative values taking the deformation of the layer at a stress of 1.0 MPa per unit. Let us designate the adopted value by the coefficient of stress influence on the layer deformation (K_σ). The dependence of K_σ on stress is shown in Fig. 6.

Table 6

Dependences of layer deformation on stress for different fractions

Thickness layer, m	Dependence $\lambda = f(\sigma)$, mm		
	2 %	4 %	6 %
Fraction 5—20 mm			
0.05	$\lambda = 6.81 ln\sigma + 8.98$	$\lambda = -1.71\sigma^2 + 11.55\sigma + 16.73$	$\lambda = -0.78\sigma^2 + 6.16\sigma + 8.53$
0.10	$\lambda = 6.95 ln\sigma + 21.9$	$\lambda = -1.73\sigma^2 + 11.85\sigma + 805$	$\lambda = -\sigma^2 + 7.9\sigma + 7.93$
0.15	$\lambda = 9.29 ln\sigma + 23.16$	$\lambda = -0.49\sigma^2 + 4.81\sigma + 2.67$	$\lambda = -2.45\sigma^2 + 16.97\sigma + 1.29$
Fraction 20—40 mm			
0.05	$\lambda = -0.27\sigma^2 + 2.59\sigma + 6.76$	$\lambda = -0.71\sigma^2 + 4.94\sigma + 6.17$	$\lambda = -1.2\sigma^2 + 8.67\sigma + 4.18$
0.10	$\lambda = 0.64\sigma^2 + 4.78\sigma + 10.94$	$\lambda = -1.14\sigma^2 + 7.42\sigma + 9.34$	$\lambda = 1.86\sigma^3 - 16.85\sigma^2 + 49.39\sigma - 13.7$
0.15	$\lambda = -3.04\sigma^2 + 21.19\sigma + 2.97$	$\lambda = -0.94\sigma^2 + 6.17\sigma + 12.42$	$\lambda = 1.46\sigma^3 - 13.17\sigma^2 + 38.77\sigma - 8.9$

The numerical value of the coefficient K_σ is given by the formulas:

— for fraction 5—20 mm: $K_{\sigma 5-20} = -0.085\sigma^2 + 0.63\sigma + 0.46$, (7)

— for fraction 20—40 mm: $K_{\sigma 20-40} = 0.04\sigma^3 - 0.385\sigma^2 + 1.25\sigma + 0.09$, (8)

where σ is stress, MPa. The correlation coefficient of the equations is 0.98—0.99.

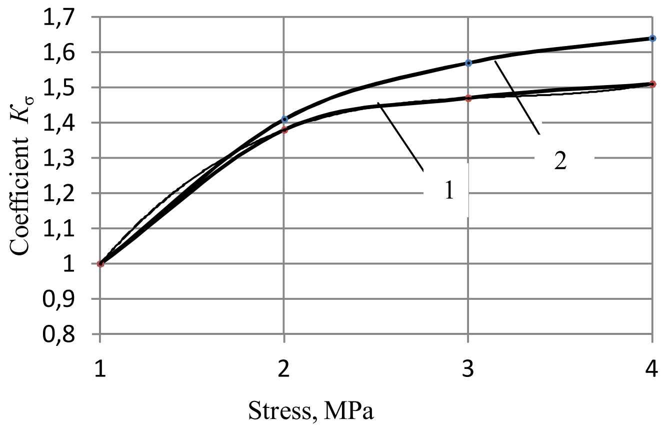

Fig. 6. Dependence of K_σ on stress: 1 is fraction 5-20 mm; 2 is fraction 20-40 mm

To reveal the effect of the layer thickness on its deformation at different emulsion contents in the mixture, the data in Table 6 is presented in relative terms taking the residual deformation of the layer at its thickness of 0.05 m per unit regardless of the stress and emulsion content in the mixture. Let us denote this value by a coefficient depending on the layer thickness as K_h. Fig. 7 shows the dependences in relative values of the coefficient K_h on the layer thickness at different percentages of the emulsion in the layers of fractions 5—20 mm and 20—40 mm.

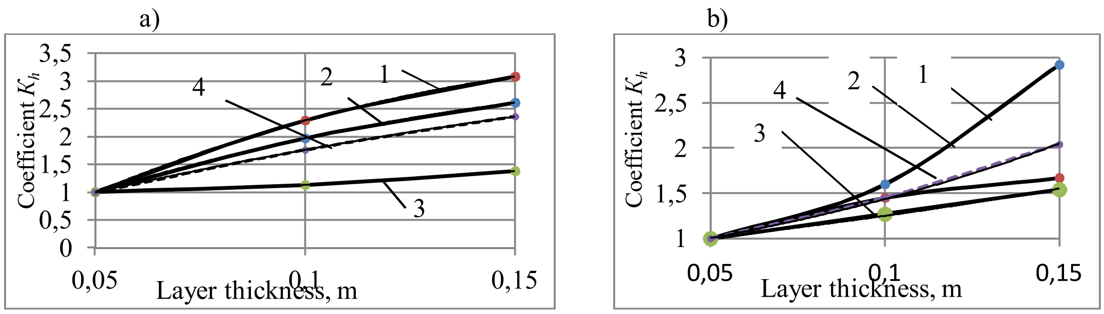

Fig. 7. Dependence of the K_h coefficient on the layer thickness at different emulsion contents:
a is fraction 5—20 mm; b is fraction 20—40 mm; 1 is emulsion content 2 %; 2 is 4 %; 3 is 6 %; 4 is general

The numerical values of the coefficient K_h at different layer thicknesses are presented in Table 7.

Table 7 takes h as layer thickness, m. The correlation coefficient of the equations is 0.99.

Based on the above values of the coefficient of influence of the layer thickness on the amount of deformation, it is seen that the size of the fractions of asphalt granuloconcrete mixtures differently affects the formation of deformation of the layer under the action of a compacting load. If when laying the mixture of the fraction of 5—20 mm with a layer thickness increasing from 0.10 m and above the value of the coefficient is stabilized, when laying the mixture of the fraction of 20—40 mm the value of the coefficient is subject to exponential dependence.

Table 7

Dependencies for determining the coefficient K_h

Layer thickness, m	Dependence	
	Fraction 5—20mm	Fraction 20—40mm
0.05	$K_h = -66h^2 + 29.3h - 0.3$	$K_{h2} = 0.57e^{10.716h}$
0.10	$K_h = -100h^2 + 40.8h - 0.79$	$K_{h4} = 0.8e^{5.13h}$
0.15	$K_h = 24h^2 - h + 0.99$	$K_{h6} = 0.812e^{4.32h}$
Generalized	$K_{hобщ} = -32h^2 + 20h + 0.08$	$K_{hобщ} = 0.7e^{7.13h}$

Based on the data in Fig. 7, it is seen that the amount of deformation of the layer under the action of load depends on the content of the emulsion in the mixture. To clarify the effect of the emulsion content on the deformation of the layer, the data from Table 6 is presented in relative values taking the deformation of the layer regardless of its thickness at an emulsion content of 2 % in the mixture, per unit and denoting this value by the coefficient of influence of the emulsion content. Fig. 8 shows the values of the K_e coefficient at different percentages of the emulsion in the mixture.

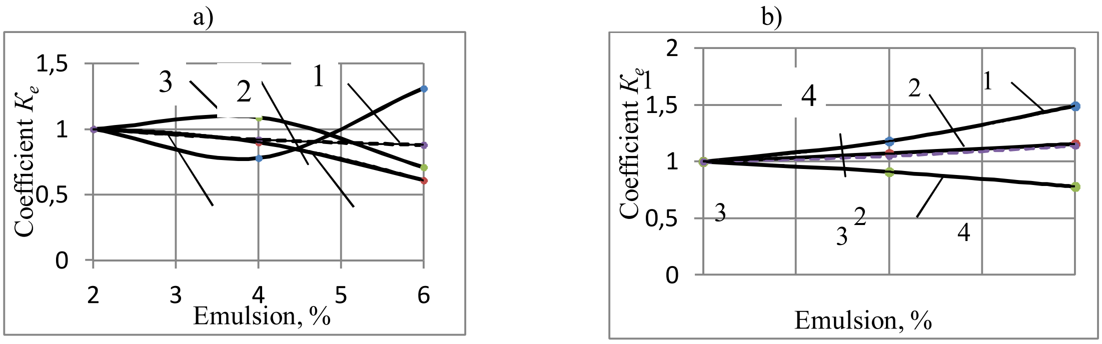

Fig. 8. The influence of the emulsion content on the deformation of the asphalt granulate layer at different emulsion contents: a is fraction 5—20 mm; b is 20—40 mm; 1 is layer thickness 0.05 m; 2 is 0.10 m; 3 is 0.15 m; 4 is general

Based on the data in Fig. 8, it can be seen that the emulsion content in the mixture affects the amount of deformation of the layer under the action of load. When arranging layers of pavement with a fraction of 5—20 mm, increasing the emulsion above 2 % leads to a decrease in the deformation of the layer in contrast to the layer of the fraction of 20—40 mm. The numerical value of the coefficients (K_e) taking into account the thickness of the layer during laying is given by the dependences presented in Table 8.

Table 8

Dependencies for determining coefficients K_e

Layer thickness, m	Fraction 5—20mm	Fraction 20—40mm
0.05	$K_e = 0.094E^2 - 0.673E + 1.97$	$K_e = 0.016E^2 - 0.0075E + 0.95$
0.10	$K_e = -0.024E^2 + 0.093E + 0.91$	$K_e = 0.0019E^2 + 0.0237E + 0.945$
0.15	$K_e = -0.059E^2 + 0.397E + 0.44$	$K_e = -0005E^2 - 0.015E + 1.05$
Generalized	$K_e = 0.005E^2 - 0.07E + 1.12$	$K_e = 0.0019E^2 + 0.0237E + 0.945$

Table 8 accepted E as emulsion content in the mixture, %. The correlation coefficient of the equations is 1.0.

Taking into account the obtained values of the coefficients K_h and K_e, the deformation of the layer, regardless of the content of the emulsion and its thickness during laying for asphalt-granular concrete mixtures is given by the formulas:

— for a fraction of 5—20 mm: $\lambda_{tot} = 9.89 K_{\sigma tot} K_{etot} K_h$, (9)

— for a fraction of 20—40 mm: $\lambda_{tot} = 10.91 K_{\sigma tot} K_{etot} K_h$. (10)

Conclusion

1. The dependences of the residual deformation on the stress at different thickness of the asphalt granulate layer and the size of the fraction are established.
2. The dependences of the deformation of a layer of different thickness on the stress at different emulsion contents are given.
3. The dependences for calculating the coefficients of influence of stress, thickness and emulsion content on the deformation of the asphalt granulate layer are presented.

References

1. Shtabinskii V. V., Skvortsov E. A., Grakovich D. P. Issledovaniya agregatnogo i zernovogo sostava asfal'togranulyata [Studies of aggregate and grain composition of asphalt granulate]. *Avtomobil'nye dorogi i mosty*, 2008, no. 2, pp. 68—72.
2. Kalgin Yu. I., Strokin A. S., Tyukov E. B. *Perspektivnye tekhnologii stroitel'stva i remonta dorozhnykh pokrytii s primeneniem modifitsirovannykh bitumov* [Promising technologies for the construction and repair of road surfaces using modified bitumen]. Voronezh, 2014. 223 p.
3. Zubkov A. F., Andrianov K. A., Antonov A. I., Odnol'ko V. G. *Tekhnologiya stroitel'stva i remonta dorozhnykh pokrytii nezhestkogo tipa s uchetom temperaturnykh rezhimov asfal'tobetonnykh smesei* [Technology of construction and repair of non-rigid road surfaces taking into account the temperature conditions of asphalt concrete mixtures]. Tambov, FGBOU VO «TGTU» Publ., 2017. 300 p.
4. Aleksikov S. V., Ermilov A. A. Sravnitel'naya otsenka odnorodnosti uplotneniya asfal'tobetonnykh pokrytii gorodskikh dorog pri razlichnykh rezhimakh raboty katkov [Comparative assessment of the uniformity of compaction of asphalt concrete pavements of urban roads under different modes of operation of rollers]. *Nauch. vestn. VGASU. Ser. Str-vo i arkhitektura*, 2014, no. 1 (33), pp. 45—53.
5. Kalgin Yu. I., Barabas' N. A. Organomineral'nye smesi s asfal'togranulyatom dlya kapital'nogo remonta dorozhnykh odezhd [Organomineral mixtures with asphalt granulate for the overhaul of road clothes]. *Vysokie tekhnologii v stroitel'nom komplekse*, 2019, no. 1, pp. 42—48.

6. Igoshkin D. G., Koshkarov V. E., Nevolin D. G., Vtyurin A. V. Ustroistvo asfal'tobetonnykh pokrytii avtomobil'nykh dorog s ispol'zovaniem asfal'togranulyata [The device of asphalt concrete road coverings using asphalt granulate]. *Innovatsionnyi transport*, 2014, no. 1 (11), pp. 35—41.
7. Panevin M. N., Kalgin Yu. I. Organomineral'nye smesi na osnove asfal'togranulyata dlya ustroistva pokrytii i osnovanii avtomobil'nykh dorog [Organomineral mixtures based on asphalt granulate for the device of coatings and bases of highways]. *Nauchnyi zhurnal stroitel'stva i arkhitektury VGTU*, 2016, no. 4 (44), pp. 120—127.
8. Pakhomova E. G., Zubkov A. F., Andrianov K. A., Monastyrev P. V. Influence of thickness and granulometric composition of granular asphalt on its strength characteristics when placing into the road pavement. Journal of applied engineering science, 2020, vol. 18, no. 2, pp. 192—197.
9. Senibabnov S. A., Andrianov K. A., Zubkov A. F. Method of Development of Technology for the Device of Road Structures Using Asphalt Granulate. Russian Journal of Building Construction and Architecture, 2020, no. 2 (46), pp. 51—70.
10. Wang P., Hu Y., Dai Y., Tian M. Asphalt Pavement Pothole Detection and Segmentation Based on Wavelet Energy Field. Journal Mathematical Problems in Engineering, 2017, p. 13. Available at: https://doi.org/10.1155/2017/1604130.