Development of proposals for the development of the design algorithm of road pavements using geosynthetic materials

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Abstract. The paper deals with the manifestation of nonlinear properties of granular materials. In addition, the analysis the possibility to take into account the influence of the geogrid on the strength characteristics of the layer is made. For a numerical experiment, a pavement structure was chosen. It was designed in accordance with the calculation methodology existing in Russia and consisting of three layers of asphalt concrete, a base layer of granular incoherent materials and a base layer of sand. For a comparative analysis of the methodology, the specified structure was also designed using the algorithm that takes into account the stress-deformed state of granular particles in the bearing course layer using a mechanic-empirical model for the determination of the elastic modulus. The topic was further justified by appropriate structural calculations, taking into account the influence of a geogrid placed above the underlying layer, both in accordance with the current legal document and according to the proposed method, which is based on the change in horizontal compressive stresses in terms of the geogrid operation. The comparison of the results showed that the current method for the design of road pavements is not enough to reflect the effect of the use of a geogrid on the strength of the structure during the calculation and, in general, underestimates the requirements for the strength of pavements.

1. Introduction
According to the Decree of the Government of the Russian Federation of May 30, 2017 No. 658 [1], the increased service life of pavements was established. However, the real tools for the increase of the inter-maintenance period of structures are still at the stage of development. The problems of pavement design are primarily based on the fact that the methods of the calculation of the entire structure, as well as individual solutions, were developed in accordance with outdated requirements. It is important to note that about forty years have passed since the core of the algorithm for the calculation of the non-rigid pavement was formed. During this time, the technical capabilities of testing and design have been improved. These facts will be the advantage of the industry in order to fulfill the task.

2. Methods
Such a constructive solution as a geogrid in the base of the pavement is intended to increase the strength characteristics of the crushed stone layer, untreated with a binder and the strength of the structure as a whole.
In order to demonstrate the effect of the geogrid, the authors calculated the pavement in accordance with Industry Road Codes 218.046-01 [2] and then the same design was recalculated taking into account the recommendations of Road industrial methodical document 218.5.002-2008 [3]. The design adopted for the calculations is shown in Figure 1. For the use in the road bed we selected a mixture S-6 (GOST 25607 [4]).

![Figure 1. Analyzed structure of non-rigid road pavement (the thickness of the layers of the structure according to the design in accordance with the ODN [2]: layer No. 1 - 5 cm, layer No. 2 - 8 cm, layer No. 3 - 10 cm, layer No. 4 - 32 cm, layer No. 5 - 40 cm)]](image)

According to the results of the calculation of the effect of the geogrid, the elastic modulus of the road bed was increased by 14.6%. The thickness of the structure was reduced by 5 cm as a result of the compensation of the strength by the reinforcement of the bed.

However, it is known [5] that the obtained values are not always justified during operation, which can be explained by the inaccuracy of the method of Road industrial methodical document [3]. The study by A.E. Merzlikin [6] described some principles of work of incoherent granular materials. The physical nonlinearity of the material and the horizontal lateral thrust were especially noted. The modulus of elasticity, which is taken today in the design of pavements, is the same for the entire layer thickness for any layout of the structure and location in the horizontal direction. In fact it changes its values depending on the position of the point in question in a particular structure. The solution of the problem in its simplified version, in which there is no need to use complex processes implemented by programs using the finite element method (FEM), is a computation using a program that implements the exact solution to the theory of elasticity.

The program is developed based on the solution of A.K. Privarnikov and it calculates stresses and strains at any point in the structure.
Having received the components of the stress tensor, using an iterative approach, we apply a mathematical model of the mechanistic-empirical method to calculate the elastic modulus in order to analyze nonlinear properties [7]:

$$M_r = k_1 \times p_a \times \left( \frac{\theta}{p_a} \right)^{k_2} \times \left( \frac{\tau_{oct}}{p_a} + 1 \right)^{k_3}$$ (1)

Here \(k_1, k_2, k_3\) – empirical nonlinearity coefficients obtained on triaxial compression units;
\(p_a\) – atmospheric pressure, MPa;
\(\theta\) – volume stress, MPa;
\(\tau_{oct}\) – shear stress on octahedral areas, MPa;

$$\tau_{oct} = \frac{1}{3} \left( (\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2 \right)^{1/2}$$ (2)

\(\sigma_1, \sigma_2, \sigma_3\) – principal stresses.

The main horizontal stresses in the longitudinal and transverse directions in the axisymmetric problem statement are considered to be equal. However, the validity of such a solution, along with the fact that they do not change with the depth of the bed, must be additionally confirmed by appropriate tests. The solution of the problem by the software package can not reflect all possible operating conditions of the granular material. Therefore, the values of \(\sigma_2\) and \(\sigma_3\) were adjusted in accordance with the studies [8]. Here it is necessary to take values corresponding to the minimum part size for testing, which corresponds to the maximum particle size in the mixture.

The empirical coefficients were borrowed by the authors from the report [9] for a mixture of mineral material, which, in accordance with the requirements of GOST [4], showed the coincidence in granulometric composition with crushed stone mixture S-6. The percentage of passes is shown in Figure 2.

![Granulometric composition compliance with GOST requirements](image)

**Figure 2.** Compliance of the granulometric composition of the studied mixture with the requirements of GOST 25607-2009
It is known that the solution to lay the supporting bed of the base from crushed stone-sand mixtures is now quite common rather than from crushed stone. This is explained by the fact that under the action of cyclic dynamic loads due to the abrasion of grains of crushed stone, its so-called additional compaction occurs, which at the stage of operation is of a non-systemic nature. In turn, the uniform sand content reduces the amount of residual deformation of the layer. Then crushed stone really works as “stress-hardening” (a material that increases strength characteristics with increasing loads) [10].

When the values of the average weighted real modulus of elasticity of the bed are obtained, the authors of this work propose to recalculate the thickness of the layer using formula 3 [3] and iterative approach:

$$h_i = \left(1.05 - \left(0.71 \times \left(E_{gen}^{(i+1)} \times E_i^{-1}\right)^{1/3} \times 1.35 \times 2 \times h_i \times \left((6 \times E_{gen}^{(i+1)})^{-1} \times E_i^{1/3}\right)\right) \times E_i^{-1}\right) \times \frac{10 \times D}{1 - \left(E_{gen}^{(i+1)} \times E_i^{-1}\right)^{1/3}}$$

(3)

According to the calculations by the indicated method, the increase in the required thickness of the structure relative to the results of calculations according to Industry Road Codes [2] is 15.6%.

The indicated method can be experimentally used in order to calculate the entire structure of non-rigid pavement. In foreign reports [9], we can find empirical coefficients for sands and soils for the design according to formulas 1 and 2 and using this algorithm, it is theoretically possible to calculate the strength characteristics of asphalt concrete [11].

Taking into account the influence of geosynthetics in this way, the key parameter is the horizontal stress within about 15 centimeters above the geogrid [5], which characterizes the so-called zones of increased rigidity, the appearance of which is provoked by the joint operation of the geogrid and granular material. Assuming that the grid makes the material particles act as a larger aggregate particles with the correct selection of rib size, it makes sense to use the stress values [8] for the larger part in relation to the lower block of the mixture layer.

3. Results
Thus, the thicknesses of the structural layers were calculated using four different algorithms, taking into account the fulfillment of the same strength criteria. The results are shown in Table 1.

| № bed | Classic calculation according to Industry Road Codes [2] | Calculation with geogrid by Road industrial methodical document [3] | Calculation taking into account special properties according to the theory of elasticity | Calculation with a geogrid according to the proposed algorithm |
|-------|----------------------------------------------------------|-------------------------------------------------|-------------------------------------------------|-----------------------------------------------------|
| 5     | 40 cm                                                    | 40 cm                                           | 40 cm                                           | 40 cm                                               |
| 4     | 32 cm                                                    | 27 cm                                          | 37 cm                                          | 33 cm                                               |
| 3     | 10 cm                                                    | 10 cm                                          | 10 cm                                          | 10 cm                                               |
| 2     | 8 cm                                                     | 8 cm                                           | 8 cm                                           | 8 cm                                                |
| 1     | 5 cm                                                     | 5 cm                                           | 5 cm                                           | 5 cm                                                |
4. Discussion
The above mentioned calculation results and conclusions about the operation of the road bed are valid only for the structure analyzed in this work, because it is known that, for example, when the thickness of the pavement layers is varied or the composition of the asphalt concrete changes, the road bed will begin to resist the occurrence of structural defects in a different mode. In addition, the results of the numerical experiment show that in order to analyze the properties of the road bed, its thickness was taken as a variation parameter. In order to introduce the algorithm into general practice, the next stage in the development of the methodology can be the testing of various compositions of non-cohesive materials for the base in laboratory conditions, as well as in the composition of structures at experimental sites.

5. Conclusion
As a result of the research it is possible to make the following conclusions:
• The modulus of elasticity of granular material depends on the location of the bed in the pavement structure and on the way how the overlying beds work. In other words, the stress-deformed state directly affects the modulus of elasticity of the granular material, the change of which has a nonlinear law.
• A geogrid under a bed of granular non-cohesive material creates the necessary wedge, which increases the strength characteristics of the layer and will even work for bending within the rib strength.
• The proposed algorithm increases the design accuracy of non-rigid road pavements using geosynthetics.

Acknowledgments
The authors express their gratitude to A.E. Merzlikin, who passed away, for his contribution to the development of the design of pavements, in particular, the issue of the use of geosynthetics, as well as for his help in the development of the studied topic.

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