Improving the resistance of road pavements to rutting

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Abstract. The aim of the article is to analyze the types of ruts formed on the surface of coatings, to study the causes of their appearance and develop construction of pavements with increased resistance to rutting. A technique is described for an experimental study of the distribution of tire passes over the width of a lane. During the experiment on existing roads, accounting points of the distribution of tire passes were organized. At each registration point, numbered strips are applied to the roadway, separating numbered sections 30 cm wide. Based on the results of an experimental study, empirical distributions of tire passes along the width of the roadway are established. The empirical data made it possible to establish discrete distributions of tire passes in width, with the help of which a correction factor was introduced into the calculation of the total number of repeated design loads. This coefficient allows calculating the number of passes in longitudinal sections located at different distances from you to the edge of the roadway or the axis of the road. As a result, central and edge parts that perceive the largest number of passages of the twin tires of the rear axles of the cars are highlighted on the tracks. To increase the resistance of pavements to rutting, constructions with unequal strength in width are proposed. The greatest strength and resistance to rutting belong to longitudinal sections on which the largest number of tires of the rear axles pass. In longitudinal sections between the ruts, the pavement is less strong. The increased strength of sections prone to rutting is achieved by creating hidden (secret) elements. Such elements are arranged in sump hole of either a subgrade or a base of granular material. Drawings of pavement construction are given.

1. Introduction
Rain water accumulates in a rut on the surface of asphalt concrete pavements, which leads to a decrease in the coefficient of traction of the tire to the coating. Moreover, for the same conditions of car movement, the traction is the smaller, the greater the thickness of the water film. Therefore, to ensure traffic safety, it is necessary to limit the rut depth to limit values [1–3].

Water flowing into a rut on coatings of granular materials penetrates inside the layer and helps moisturize soil of the subgrade and constructive layers of road pavement from crushed stone and gravel materials. Moisturizing contributes to an increase in the accumulated residual deformation [4–6], to a decrease in the parameters of shear resistance of cohesive [7–9] and special types of soils, for example loess soils [10].

A decrease in the shear resistance parameters of the Mohr – Coulomb criterion (cohesion and angle of internal friction) leads to an increase in shear stress [11] and a decrease in shear strength, Safety Factor (SF) [12, 13], the first critical load [14], and the ultimate pressures for different types of loads [15–19]. In addition, an increase in humidity causes a decrease in soil deformation modules [20, 21].
In that case, any calculation method selected for design leads to the need to increase the thickness of the pavement [22].

Residual deformations accumulated by soils and materials, as well as wear out of the asphalt concrete pavement leads to the formation of ruts. Depending on the material used in the pavement coating, ruts can be divided into two types, and each type into three varieties. Figure 1 shows all varieties of ruts [23–25].

![Varieties of ruts on asphalt concrete pavement and coating of granular material](image)

**Figure 1.** Varieties of ruts on asphalt concrete pavement [23, 24] and coating of granular material [25]: a – Structural rutting; b – Instability structure; c – Surface wear rutting; d – compaction deformation in layers of granular materials; e – shear deformations in layers of granular materials; f – shear deformation in the subgrade 1 – layers of asphalt concrete pavement; 2 – bearing and additional base layers; 3 – subgrade.

From the analysis of figure 1 it follows that the reason of the formation of a rut may be the deformation of all layers of pavement figure 1a, or mainly only one layer figure 1b - figure 1f. Ruts caused by deformation of compaction and shear of the material of the upper layer are called the surface ruts, which corresponds to the Instability structure figure 1b. Such a rut is caused by deformation of the sealing or shear of the material in the coating, or by wear out of the coating.

The rut caused by deformations of the material in the base of the pavement or soil of subgrade is called the deep rut. The goal of our work is to develop constructions of pavements resistant to the formation of deep ruts. For this, it is necessary to determine the longitudinal sections of the lanes of roadway experiencing the greatest number of car passage, and to develop construction of road pavements with unequal strength along the width of the lanes.

2. Materials and methods

Research must begin with a study of the nature of the distribution of tire passes across the width of the lanes. To do this, experimental studies have been carried out on exploited roads with parameters of the roadway that match the requirements of building norms and rules of the Russian Federation. On the coating along the axis of the roadway, longitudinal strips were applied, which separated the numbered sections. Numbering of sections is made from the axis of the roadway to the edge. For clarity, in figure 2a, an illustration of the marking of the Omsk-Pavlodar highway lane is given. In the course of the experiment, a video was taken that recorded the passage of vehicle tires over numbered sections. Figure 2b shows the moment of tire passage through the numbered sections.
Figure 2. Experimental study: a – numbered sections; b – passage of the rear axle tires on numbered sections.

In the process of passing cars, video recording of tire passes along numbered sections is performed. Video recording fixes the numbers of the lanes within which the tires of a vehicle pass when it passes through a section of the road. The data on the distribution of tire passes convert to the passages of the rear axle of the car, the wheels of which are equipped with paired tires. When passing such a car, the center of each tire was within a strictly defined numbered strip. For cars with a rear axle equipped with one tire for each wheel, two numbered lanes were fixed, within which the passage was carried out. Thus, independently of the number of tires with which the rear axles of vehicles are equipped, the passage of each vehicle made it possible to distinguish 4 numbered lanes that absorb the load. Therefore, 100% of cars that have passed through the cross section in total give 400% of the lanes that absorb the load from the tires of the rear axle, of which 200% of the impact is on the tires of the right wheel and 200% is due to the passage of the left wheel.

Vehicles subject to study of the distribution of tire passes along the width of the roadway were divided into three groups. The first group consisted of heavy and very heavy trucks, truck tractors, dump trucks, road trains. The second group includes medium and light trucks, and the third group includes buses.

Figure 3 shows the results of experimental studies of the distribution of tire passes of heavy trucks, dump trucks, truck tractors and road trains along the width of the roadway of a II technical category highway with axial and edge horizontal road markings shown in figure 2a.
Figure 3. Schedule distribution of tire passages along the width of the road lane of the II technical category road: 1 and 2 – outside and inside tire of the left wheel; 3 and 4 – inside and outside tire of the right wheel; 5 – summary epure.

From the analysis of the data in figure 3, it follows that the main number of tire passes is located within 90 cm wide lanes, in which the most loaded are the central parts 30 cm wide, which absorb up to 80% of the tire impacts of the total number of loads. Edge lanes with a width of 30 cm perceive up to 50% of the impacts of tires each. By the remaining numbered sections, 20% of the impacts of tires pass through.

The diagrams of the distribution of tires passes in figure 2 are presented in the form of an empirical discrete distribution, but they can be processed by the methods of mathematical statistics by selecting the theoretical law of the distribution of passages for each tire. In this case, the distribution will be continuous.

The authors consider it possible to calculate the number of loads by using correction factors specified by an empirical distribution similar to the distribution shown in figure 3 (summary epure). Such data can be used to predict the depth of the rut, moreover, these data are suitable for use in any known calculation method. This is confirmed by the fact that empirical, mechanical-empirical and analytical methods for predicting the depth of the rut, regardless of the type of mathematical apparatus used in their development, contain a function of the number of loads.

Focusing on the dependencies of ODN 218.046-01, formulas for calculating the total number of applying of loads in different sections of the cross profile of the lane we give in the form:

\[
\sum N_p = f_n \cdot \sum_{m=1}^{n} (N_{im} \cdot K_i \cdot T \cdot 0.7) \cdot S_{mc} \cdot k_n \cdot k_m.
\]  

(1)

where \(f_n\) – coefficient taking into account the number of lanes and the distribution of traffic along them; \(n\) – the total number of different types of vehicles in the transport stream; \(N_{im}\) – daily intensity of type \(m\) vehicles in the first year of service (in both directions), auto/day \(m\); \(S_{mc}\) – the total coefficient of bringing the impact on the pavement of a vehicle of type \(m\) to the calculated load; \(T\) – estimated number of estimated days in a year corresponding to a certain state of deformability of a structure; \(K_i\) – summation coefficient; \(k_n\) – coefficient taking into account the probability of deviation of the total movement from the average expected; \(k_{ni}\) – we introduced the distribution coefficient of the passage of tires of cars of type \(m\) along the width of the lane, determining their share in the center of the \(i\)-th section, numbered during the experiment figure 3.
The value of introduced by us, the distribution coefficient of the passes of tires less than 1. Therefore, in any section allocated within the lane width, the total number of applying of the design loads is less than according to the regulatory document.

In each section allocated within the width of the lane, the total number of a applied loads not the same. Therefore, the surface of the cross profile experiences unequal residual deformations in width. This gives rise to the idea of increasing the uniformity of deformation of pavement within the lane due to the making of unequal strength on width of the structure.

For such conditions N. A. Fidlovsky for agricultural roads he proposed the constructions of pavement with unequal strength in width. In this construction the crushed stone base within the lanes with the largest wheel passage is reinforced with bitumen by the impregnation method. The construction has limitations due to the fact that the method of impregnation allows you to arrange a layer with a thickness not more than 8 cm. This reinforced of base is suitable for a limited number of loads applied.

According to the authors, hidden rut elements arranged in trenches cut in the base from granular material or in soil of subgrade are more effective.

Modern equipment allows you to excavate trenches with different cross profiles, and finalizing the trench according to the template allows you to achieve a complete copy of the shape of the element, calculated during design. Therefore, for construction, we offer two varieties of pavement construction including reinforcing elements of unequal thickness across the track width. The cross sectional shape of the element can be set in the form of a trapeze, as shown in figure 4. This figure shows two constructions directed at reducing the depth of the rut formed by deformation of the layer of granular material in figure 4a, and the rut due to deformation of the soil of the subgrade in figure 4b.

The specificity of our proposals is that in the central part of the track in which the rut depth of equal strength across the width of pavement has the maximum depth, the hidden rut element has the greatest thickness. In these sections, the thickness of the element is calculated with the value of the coefficient of distribution of tires passes \( k_{mi} = 0.8 \). In the edge parts of hidden rut elements, their thickness is calculated at a coefficient value \( k_{mi} = 0.5 \). To check the sufficiency of the thickness of the pavement between the rut the coefficient value – \( k_{mi} = 0.2 \). Here we note the fundamental difference

\[ \text{Figure 4. Road pavements for road of II technical category with hidden rut element: a – with creation a hidden rut element in the base of granular materials; b – with creation a hidden rut element in the subgrade; 1 – coating layers and bases from materials treated with an organic binder; 2 – layers of granular materials; 3 – hidden rut element from material or soil treated with a binder; 4 – subgrade.} \]
between our proposal and the construction of N.A. Fidlovsky. Idea N.A. Fidlovsky is aimed at strengthening the granular base within the limits of the tracks of road. This idea is based on the fact that the crushed stone base of pavement, calculated in accordance with all the rules of the normative method, is strengthening by the method of impregnation along the tracks. In this case, there is some increase in the material consumption of the construction of road due to the impregnation with bitumen, which is not required in the normative calculation on strength. Our proposal is that pavement with hidden rut elements is calculated at three different numbers of total applied loads. These total numbers of applied of calculated loads are: for between the rut space 20% from the number of calculated loads according to the normative methodology, for the central and edge parts of the tracks, respectively, 80% and 50%. In this case, the material consumption of the construction decreases, and by aligning the value deformations of the surface of the layers along their width, the rut depth decreases. Of course, with this calculation, all conditions of strength and frost resistance, regulated by the normative document, must be satisfied.

The reinforcement of the base layers from granular materials in figure 4a, is aimed at preventing shear deformations in this structural element. Such strengthening can be applied when deforming the surface of the coating shown in the figure 3a and figure 3b. The same construction can be applied to reduce the material consumption of road pavements with a multi-layer thick asphalt concrete coating that accumulates deformations in the upper asphalt concrete layers in figure 1d and figure 1e. In this case, the hidden rut element can be made of asphalt mix, having obtained, after its overlap with one or two layers of asphalt concrete with the same thickness in width, a large total thickness of the asphalt layers only within the tracks, and in the space between the rut the thickness of such layers will correspond to light or transition type of pavement. In such constructions, the width of the hidden rut element on top is accepted to be 90 cm, that is, it is equal to the width of the track in the most deformable part. The width of the thickest part of the element on the lower side is 30 cm, that is, it is equal to the width of the track with the greatest number of repeated loads.

Hidden rut element in the subgrade have a width on top of 1.5 m, and the width of the thickest part of the element on the lower side is 60 cm. In this case, the distributing ability of the pavement is taken into account, that is, its ability to redistribute the load on an area increasing in depth. The soil of the subgrade located between the hidden rut elements experiences a favorable stress-strain state close to virgin compression. This state arises as a result of the proximity of the elements from each other at a distance of 30 cm on figure 4b. As a result of this, the soil between the hidden rut elements operates under conditions of a significant limitation of lateral deformations. Therefore, an increase in the width of hidden rut elements and the actual linking of the width with the distributing ability of the pavement are inappropriate.

3. Results
Both proposed construction have two advantages, they reduce the material consumption of pavement and increase the uniformity of deformation of pavement along the width of the lanes, thereby contributing to a decrease the rut depth.

As a result of the close proximity of the hidden rut elements from each other, the soil of the subgrade between them experiences virgin compression, in which the stress deviator has the least value compared to other stress states of the subgrade due to triaxial compression arising both from the moving load and from its own weight of pavement. This contributes to a significant reduction in deformation in the soil.

As a disadvantage, we note the increased laboriousness of the creation of the pavement element with hidden rut elements, but they can be arranged using mechanization means. The possibility of mechanization of work on the creation of hidden rut elements makes these constructions real in the foreseeable future. Therefore, it is necessary to set tasks, the solution of which will allow the introduction of the hidden rut elements in construction.

For the successful implementation of hidden rut of pavement, it is necessary:
– to develop a new one or to justify choosing a well-known method for calculating the rut depth, which is necessary to check the criterion for rutting when calculating the thickness of hidden rut elements and the thickness of pavement.

– set the values of the reduction coefficient of transport loads to the design load for all types of vehicles. This will make it possible to more accurately determine the total reduction coefficient \( S_{tc} \) in formula (1), and, therefore, the authenticity of calculating the total number of applied loads and the authenticity of calculating the hidden rut of pavement will increase.

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