# DESIGNING AND CONSTRUCTION OF ROADS, SUBWAYS, AIRFIELDS, BRIDGES AND TRANSPORT TUNNELS

DOI 10.36622/VSTU.2021.51.3.007
UDC 625.8

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## EXPERIMENTAL STUDIES OF WEARING AND TEARING OF ASPHALT CONCRETE SURFACING UNDER THE ACTION OF WATER PRESSURE IN MICROPORES

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**Statement of the problem.** The goal of this study is to identify the effect of wet surfacing on its wear and tear. The mechanism of influence of transport loading in the presence of moisture and experimental methods of measurement of its influence on wear and tear of the top layer of asphalt concrete are discussed.
**Results.** The contribution of the presence of moisture in the upper layer of the pavement to its wear and tear in the form of track formation was identified, and the hydrodynamic effect of water in the micropores of the pavement was investigated. Experimental data on the values of water pressure in the pores of the asphalt-concrete pavement in the moistened state under the action of the wheels of the moving traffic flow were obtained. Therefore it became possible to identify the maximum values of the pressure effect, the depth of penetration of the fluid pressure front and its effect on the destruction of the surfacing.
**Conclusions.** The analysis of the data showed not only the presence of brittle fracture, but also the impact of moisture moving in the pores of asphalt concrete, exceeding its structural strength. Using experimental data, regression dependences of the wear and tear value on the standard flow parameters were obtained. For the operated surfacings regression dependence enables one to predict the size of wear and tear for the whole life cycle of the road.

**Keywords:** road surface wear, water pressure in a porous medium.

**Introduction.** A lot of scholars have been researching the field of vehicle interaction and surfacing: A. A. Khachaturov, A. K. Birulya, N. Ya. Govorushchenko, R. V. Rotenberg, F. I. Bomhard, N. Moppert and other foreign scientists [ 7, 8, 10—15, 17, 18].

In experimental studies [3, 4], measurements were conducted on dry surfacings or in the presence of low moisture content, which did not enable researchers to separate dry and wet wear in the presence of moisture.

In [5], integral indicators of the smoothness of the surfacing were used viewing them in the context of the additive effect of the transport flow, which did not allow one to understand the mechanism of different speed wear and tear of the dry and wetted surfacing either. The authors assumed there was some pressure in the micropores of the upper layer of the road, but the existing methods and techniques for identifying this pressure have not been sufficiently tested, so qualitative methods for identifying the humidity and porosity of asphalt concrete have been employed [6].

The development of the theory of failure of materials under the action of a high-velocity water jet [12] has shown that the pressure emerging at the point of concentration of the material stress might cause further defects in the form of a crack. This phenomenon is called the «waterjet» effect known to specialists in the industrial processing of materials by means of a jet of water. A similar failure takes place with the piston effect along the pore line of the upper layer of road material under the pneumatic action of the tire. In this case, the maximum value of the hydrodynamic pressure exceeds that of the strength of the material itself or that of the tensile strength of the mineral component [17]. Emerging internal stresses do not only cause the entrainment of the mineral component, but also the formation of a network of micropores and cracks.

While vehicles are moving on the road, the impact of wheel tires on asphalt concrete has a different nature for the dry and wet condition of the road surface due to pores and microcracks. In the moistened state, the bubble structure of the aqua trace is indicative of the microcirculation of water in the upper thin layer of the road surfacing. The resulting pressure in the area of contact of the wheel with the road is the cause of failure of the upper layer of the surfacing, which is washing of its mineral components. According to the performed mathematical modeling [9], there is wear and tear resulting from the impact of the wheels of moving vehicles in the presence of water on the surfacing («waterjet»). In order to verify the data obtained by means of mathematical modeling, a technique was developed and an original system for measuring the pressure in the pores of the surface of the pavement while a vehicle is passing with simultaneous registration of the deflection of the road structure was set forth.

The object of the study are asphalt concrete pavements of roads under the influence of traffic.

The subject of the study is the process of wear and tear of the upper layer of the road surface from the resulting water pressure in the micropores in the area of contact of the wheels with the road.

**1. Identifying deformations and wear and tear of the road surface in dry and wet state.** Experimental studies are based on the common and private techniques that enable the maximum information about the processes of wear and tear of the asphalt pavement to be measured and obtained. The maximum amount of wear and tear on the width of the road surface under study is observed on the section with a track. Tracks are formed due to staining of the mineral part of the road surface and plastic deformations of asphalt concrete under the action of repeated loads from the wheels of vehicles (Fig. 1).

**Fig. 1.** Photo of a section of the road surface with a defect in the form of a track

Sensors are set up on the selected section of the road in order to measure the amount of road wear and tear. To ensure the smoothness and high accuracy of the periodicity of the markers, their strictly vertical arrangement uses a template in the form of a long wooden rail with predrilled holes on the machine. Fig. 2 shows the layout of the markers in the asphalt surfacing.

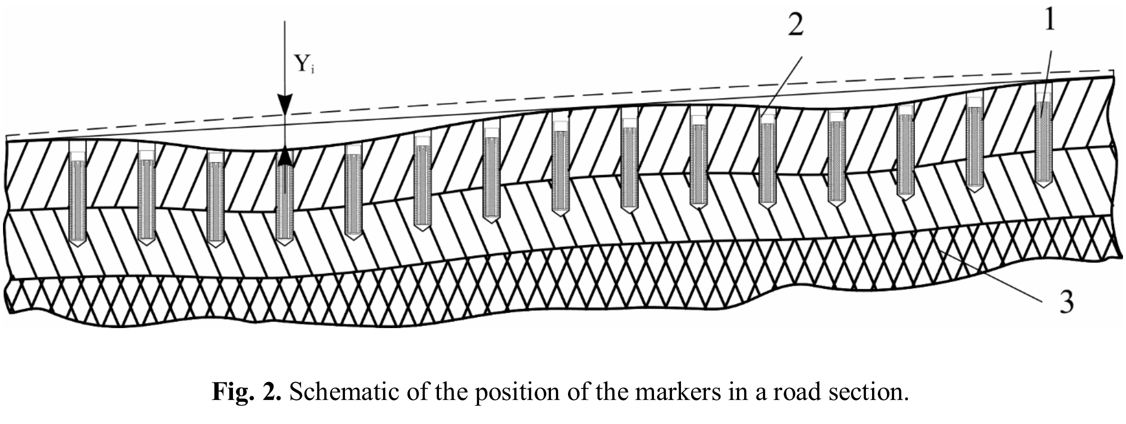
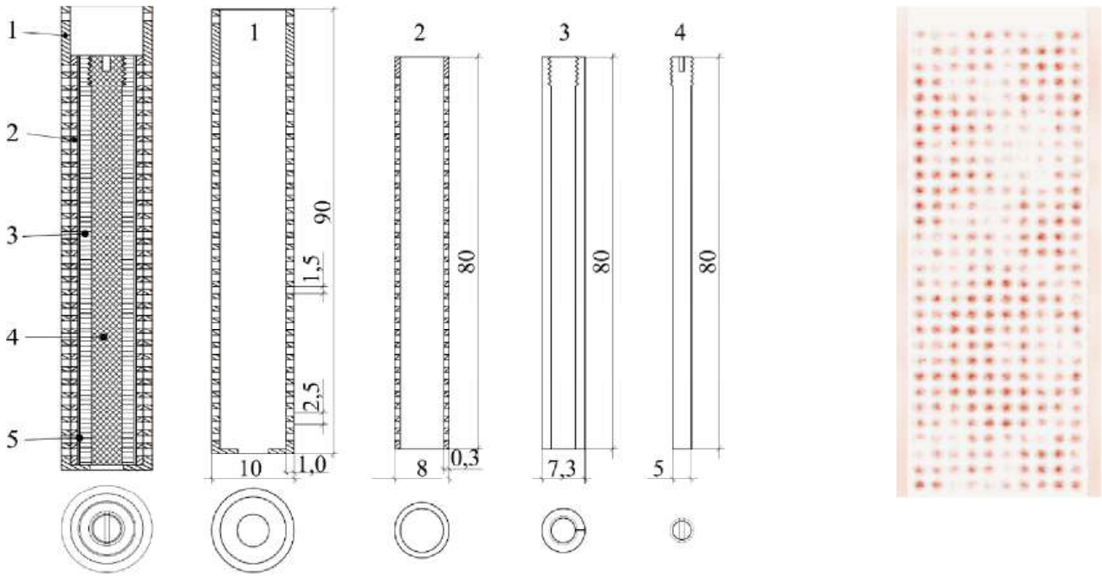



**Fig. 2.** Schematic of the position of the markers in a road section.

1 is a marker; 2 is the road surfacing; 3 is the lower layer

The drilling depth of the asphalt surfacing corresponds to that of the position of the markers. Particles and chips emerging during drilling of asphalt concrete are removed by blowing with compressed air. Using a pin setter, the marker is inserted to a depth of 15 mm from the top face. The diameter of the hole for the markers is 10 mm, the pitch of the markers for measurements is 10 cm. In order to protect the channel and the marker from water, dirt and dust, it is closed with a silicone rubber stopper and filled with a bitumen one.




a) b) c)

**Fig. 3.** a) structure of a marker sensor; b) composites; c) measuring film;
1 is an external sleeve; 2 is a thin-walled tube; 3 is a sleeve — clamp;
4 is a fixing rod; 5 is a film

Fig. 3 a) shows a drawing of the resulting marker sensor, which is a thin-walled tube with a diameter of 8 mm and a length of 80 mm made of stainless steel with a wall thickness of 0.25 mm, position 2. In the tube wall holes are made with a diameter of 1.25 mm, with a vertical and horizontal step, 2.5 mm respectively. The inner surface is polished thoroughly. A caprolon sleeve with an outer diameter of 7.3 mm, position 3, is inserted into this tube. A slot is made in the sleeve for fixing the barosensitive film, Fig. 3 c). For effective clamping, a fixing rod with a diameter of 5 mm is screwed, position 4. Notches are made for the correct positioning of the sensor. Prior to surfacing, the fabricated markers had been tested for sensitivity to hydrostatic pressure in various materials. In order to increase the accuracy of the measurements, the sensors were calibrated with an autoclave setup.

The accuracy of measuring the wear and tear of the surfacing $\Delta Y_1$ is 0.01 mm from the surface of the asphalt to the lower edge of the measuring line, and to the top of the reference marker — $\Delta Y^2$. The deformation values $\Delta S_1$ and $\Delta S_2$ are measured for recording changes in the deformed state of the surfacing. In the in-house processing of the results, the measured values are processed by means of the methods of mathematical statistics. In this case, $\Delta S_1$ simultaneously identifies the amount of plastic deformation and the wear and tear. A caliper is used to measure the distance from the lower face of the measuring rail to the end of the marker.

The amount of deformable material and wear and tear is proportional to the cross-sectional area $S$ which can be given by the formula:

$$S = \frac{\alpha}{2}\sum_{i=1}^{N}\left[\left(\Delta S_{2i} + \Delta S_{2(i+1)}\right) - \left(\Delta S_{1i} + \Delta S_{1(i+1)}\right)\right],$$

where $a$ is the distance between the neighboring markers.

The average value of wear $\xi$ in the examined section for any period of road operation is given by the formula:

$$\xi = \frac{1}{2}\sum_{i=1}^{N} = \left[\left(\Delta Y_{2i} + \Delta Y_{2(i+1)}\right) - \left(\Delta Y_{1i} + \Delta Y_{1(i+1)}\right)\right] -$$
$$-\frac{1}{2}\sum_{i=1}^{N} = \left[\left(\Delta Y^{'}_{2i} + \Delta Y^{'}_{2(i+1)}\right) - \left(\Delta Y^{'}_{1i} + \Delta Y^{'}_{1(i+1)}\right)\right],$$

where $N$ is the number of cars passing through the section; $Y$ is the distance from the measuring line to the marker in the initial position; $Y'$ is the distance from the measuring line to the marker after passing of another car.

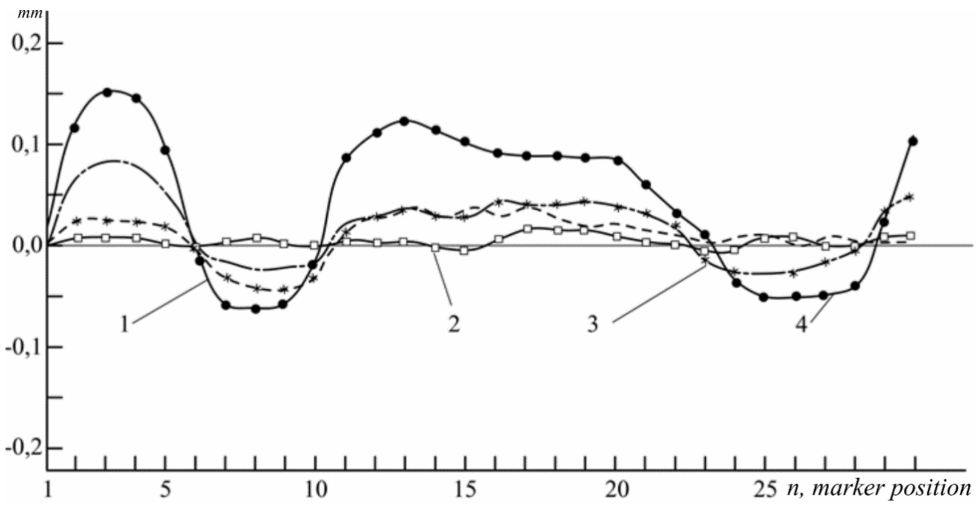



**Fig. 4.** Graphs of track change and wear and tear on the road surface in dry and wet state.
1 is the track depth; 2 is the difference of track depth for two sections of the road;
3 is the difference between the wear and tear on the dry and wet roads;
4 is the difference between the values of the wear and tear of the wet and moist road surfaces

Fig. 4 shows the values of the geometric parameters of the track in the form of wear and tear on the sections over the month. The profile clearly indicates both areas of plastic deformation in the form of the track and protrusions, and areas with wear and tear, in the absence of the previous ones. The impact of traffic flow on the road structure in the initial period is manifested in minor deformations, while subsequent operation reveals a drop in the wear and tear. At the same time, a larger amount of wear and tear is manifested in the tracks themselves, and as water is retained in these areas more, it can be argued that the presence of moisture in the tracks has an extra effect on the wear and tear of the surfacing.

The analysis of the change in the geometric position of the points of the upper layer of the surfacing and the markers showed there are not only longitudinal deformations, but also transverse ones. It is possible to separate plastic deformations and wear and tear on the clamps if the general change of the position of the material of asphalt concrete in the section and change of the area are observed given that it is constant in the initial condition.

**2. The method of identifying the amount of pressure in the pores and wear and tear in the wet surfacing.** In order to verify the obtained data of mathematical modeling, a method for identifying the water pressure in the micropores while a vehicle is passing on the surfacing with simultaneous record of the deflection of the road structure was developed [5, 16]. Using this technique, data were obtained based on the parameters of the dynamic effect of water and its effect on the amount of wear and tear and irreversible deformation of the surfacing.

In order to assess the impact of water on the wear and tear of the surfacing, two sections on roads without branches and changes in the technological cycle of road construction were selected. The markers were placed on each section, fixing the applied pressure, as well as their geometric position in the surfacing material. In order to simulate different cases of the surfacing state, each section was put in one of three states: dry, moistened and covered with a thin layer of water for a period of time.

Measurement and recording of hydrostatic pressure in the surfacing using barosensitive films set up in the marker sensors was conducted in the following order:

- extraction of a strain film from the marker;
- washing of the strain film and drying at $40^0$C;
- application of a straightening composition, marking and registration;
- laying on the scanner with a clip of a reflective film and drawing of immersion liquid;
- scanning (at least three times) and saving for further processing;
- image processing in the mathematical package MATLAB: calibration correction, analysis of the brightness of pixels and their area, statistical analysis of the pressure distribution;

- construction of correlations;
- construction of a vertical pressure profile;
- construction of a circular pressure profile.

Measurement of geometrical parameters of the surfacing and extraction of the marker-sensors is performed following several stages of humidification of the sites and passing of vehicles, followed by new films beign set up for the next stages of the measurement.

Fig. 5 shows a graph of changes in the wear and tear over the month on two selected sections of the road in different operating conditions: dry - lower curves; periodically moistened — average curves; with a constant humidity - upper curves. The analysis of the change in the wear and tear in different sites shows that in the presence of moisture on the surfacing, the wear and tear rate goes up. At the same time, a larger amount of wear and tear with the formation of ruts is manifested in the areas where water is retained more. This serves to indicate the effect on the wear and tear of the surfacing on the moisture in the tracks.

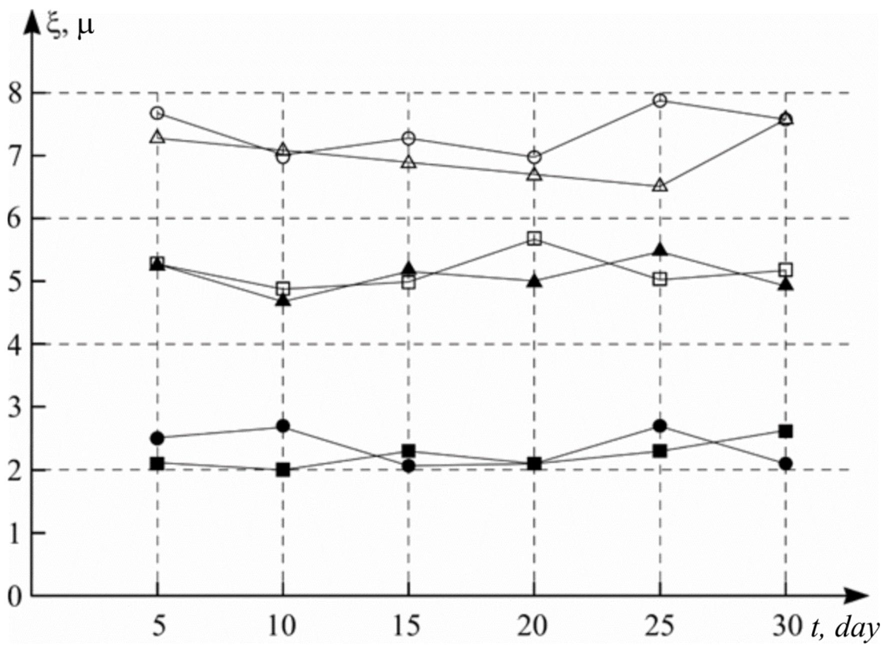



**Fig. 5.** Graphs of wear and tear change on the 1st and 2nd sections of the surfacing in their various operational condition (dry, periodically moistened, with a constant humidity)

The analysis of experimental data related to the wear and tear of the surfacing showed the presence of local values, and the form of the obtained curves is quadratically dependent on the speed of the transport flow. At the same time, the measurement of vehicle weight, record of the pressure exerted by the tires of the wheels showed there is a logarithmic dependence of the maximum wear and tear on the pressure. Obviously, the quadratic dependence on the speed of movement is related to the kinetic energy of the vehicle and thus its release in the form of failure, while a logarithmic dependence is associated with its dissipation in the contact zone. As a result of the analysis, regression dependences of the wear and tear on the characteristics of the transport flow in the form were obtained

$$\xi = -K_1 \cdot \upsilon^2 + \left(K_2 \cdot \ln\left(P_{tire}\right) + K_3\right) \cdot \upsilon - 0.01,$$

where $\upsilon$ is the speed of the vehicle, m/sec; $P_{tire}$ is the pressure in the tires, MPa.

The coefficients of the resulting regression dependence are shown in Table. The change in the coefficients of the regression equation is caused by a study on two types of surfacings. At the same time, the more porous showed a higher amount of wear and tear, by 5—6 %, and lower speeds leading to failure of the surfacing.

Table

Coefficients of the regression equation

| Surfacing | $K_1 \times 10^3$ | $K_2 \times 10^3$ | $K_3 \times 10^3$ |
|---|---|---|---|
| Asphalt concrete ЩМА-20 (porosity 3%) | –1.1 | 16.1 | 61.6 |
| Asphalt concrete Б-2 (porosity 5%) | –1.2 | 15.4 | 54.2 |

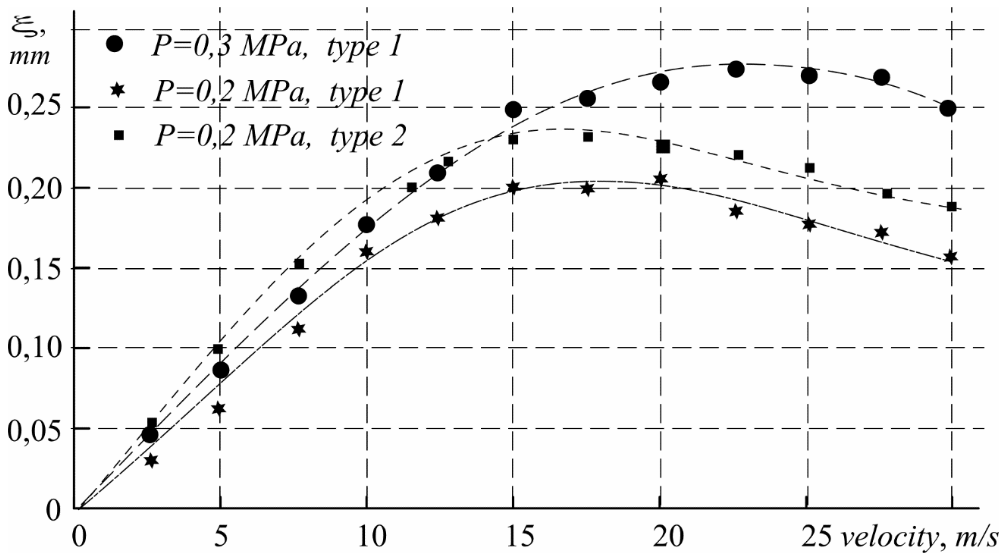



**Fig. 6.** Wear and tear of different asphalt surfaces

Fig. 6 shows the experimental values of wear and tear for different asphalt surfacings, depending on the speed of vehicles with different tire pressures. The maximum wear and tear has moved to the range of lower velocity values, and there is a drop at higher wear and tear values, indicating a higher porosity of the surfacing.

The above connection between the speed of the vehicle and the intensity of wear and tear is expressed in the operation of friction on the dry and wet surfaces. As the intensity of wear and tear is identified based on the operational condition of the road surfacing, the impact on the surface depends not only on the internal pressure in the tire, but also on the course of action taken to reduce its water absorption.

**Conclusions.** A new system for recording the pressure in the pores of the upper layer of asphalt pavement has been developed allowing the maximum pressure in the contact zone of the sensor to the depth of its installation to be identified. For the first time, experimental data have been obtained based on the values of water pressure in the pores of the asphalt concrete surface when it is moistened under the action of the wheels of a moving traffic flow. Therefore it became possible to identify the maximum values of the pressure effect and the depth of penetration of the liquid pressure front. The analysis of the resulting data showed not only the presence of brittle fracture, but also the impact of moisture moving in the pores of asphalt concrete that exceeds its structural strength. Once the temperature reaches 15 °C, brittle fracture becomes comparable to plastic deformations. Using the experimental data, the regression dependences of the wear and tear value on the standard flow parameters were obtained. For operating surfaces the regression dependence allows the size of wear and tear to be predicted for the entire life cycle of the road.

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