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

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THE MODELLING OF ROAD DEFORMATION UNDER THE ACTION OF A TRAFFIC FLOW

Problem statement. The problems of deformation of pavement under the influence of a traffic flow are examined. The results of numerical simulation of dependence of a road carpet deflection on different configurations of the traffic flow are presented subject to physical principles of formation of the stresses, movements, and volume strains.
Results and conclusions. Conducted numerical modeling of transport flow effect on road structure revealed the increase in surface deflection compared to a single vehicle. The revelation of relationship between road deformation and action of transport flow will make it possible to determine operation conditions of road surface and to recommend measures on road site repair and reconstruction.

Keywords: road structure, elastic deflection, deformation, vehicle.

Introduction. In the course of operation of roads with asphalt concrete pavement transport stream causes road surface deflection, plastic deformation, and wear. There is a correlation between asphalt concrete pavement deformation and rut formation. At the same time, the effect of transport stream on road surface deformation is as yet imperfectly understood and is topical direction of scientific studies.

The novelty of the study is in detection of relationship between road deformation and transport stream impact. This allows us to determine operation parameters of road surface and to recommend measures on repair and reconstruction of the road site.

The diversity of road structures and application of each layer of assorted materials result in various deformations under the action of transport load. The data obtained detected the presence of relation between static and dynamic impact on road deformation. The subsequent assessment of elastic deformation which exceeds maximum value showed the emergence of plastic and, therefore, irreversible deformation. The relation between irreversible deformations of asphalt concrete pavement and geometric parameters of a rut was observed at the sites of high traffic intensity. A rut in a road pavement can cause traffic accident.

The observations on the effect of the load on road structure were conducted by foreign and domestic researchers [1] in a wide range of different parameters of highway operation and showed the correlation between static and dynamic impact of a load on elastic deformation and, as a result, on residual deformation.

The analysis of operation conditions of highways detected the presence of a rut which is a longitudinal deformation. Its geometric parameters (rut depth and width) can vary depending on transport influence.

In modern scientific literature, the problem of transport flow impact on a road structure with corrected value of modulus of elasticity has not been adequately addressed. To obtain the value of elastic deformation, it is essential to study stress-strain state of road pavement and to develop by means of numerical modeling, and to calculate maximum values of elastic defomation.

The value of road deformation can be assessed only with consideration for the parameters of transport flow. To this end, it is necessary to determine static parameters of transport flow intensity.

Let N be traffic intensity, car/day, then,

$$dNx = N_{y\max} \cdot dx$$

loads тwill be applied to the road lane of width dx in a day.

Let us consider transport flow on a single-lane road, that is, at traffic without overtaking. The number of cars at the road site in a range of length from x_1 to x_2 corresponds to the density of cars $p(x, t)$ in a period of time t (1):

$$Nx = \int_{x_1}^{x_2} \rho(x,t)dx . \tag{1}$$

Similarly, the number of cars in a period *dt* is (2):

$$Nt = \int_{t_1}^{t_2} \rho(x,t)dt\,. \qquad (2)$$

Having determined the flow parameters, let us find the action of vehicles on road pavement subject to the condition of elastic interactions in structure. With respect to the effect of accumulation of damages caused by these loads applied at a distance x from the calculated section, this action is equivalent to the action of loads applied in a cross-section *dNnp*, if the following condition is true (3):

$$dNnp = N \cdot y_{\max} \cdot \left(1 / \left[1 + \left(\frac{x}{r_0} \right)^2 \right]^{\frac{2}{m}} \right) \cdot dx\,, \qquad (3)$$

where m is the ratio of fatigue dependence of asphalt concrete; r_0 is the radius of deflection bowl, cm; $h_э$ is the width of pavement, cm;

$$h_э = 1{,}1 \cdot h \cdot \sqrt[3]{\frac{E_n}{E_0}}\,,$$

where h is the thickness of pavement, cm; E_n, E_0 are the modules of elasticity of pavement and road base, kg·sec/cm^2.

By integrating over the whole width of carriageway, we obtain reduced traffic intensity (4):

$$Nnp = N \cdot y_{\max} \int_{-\infty}^{+\infty} \frac{dx}{\left[1 + \left(\frac{x}{r_0} \right)^2 \right]^{\frac{2}{m}}} = N \cdot y_{\max} \cdot r_0 \cdot B\left(\frac{1}{2}; \frac{4-m}{2m} \right), \qquad (4)$$

where B is the beta function which ranges from 0.15 to 0.30 (the limits of change in m).

The road structure whose diagram is applied in design is a multilayer anisotropic system which is subject to the basic fundamental principles and is attributed to the physical properties of applied materials. Technological properties of materials take on specified characteristics which manifest themselves in anisotropic properties of materials from which building layers are constructed. These materials acquire long-range order parameters and physical and mechanical characteristics equivalent to a given temperature with consideration for the properties of a given material. The findings of investigations allowed us to obtain the relationship between rebound deflection under the action of transport load, the number of loads, and rut depth. Existing correlation is of interest in studying the influence of transport flow on rut formation.

In present paper, the part of results of numerical modeling of road pavement deflection under the action of different configurations of transport flow is presented. The road structure (Fig. 1) is considered as a structural model. The structural model consists of the layers (see Table 1). The structure meets the requirements to the value of design load and geometric parameters and corresponds to class II road.

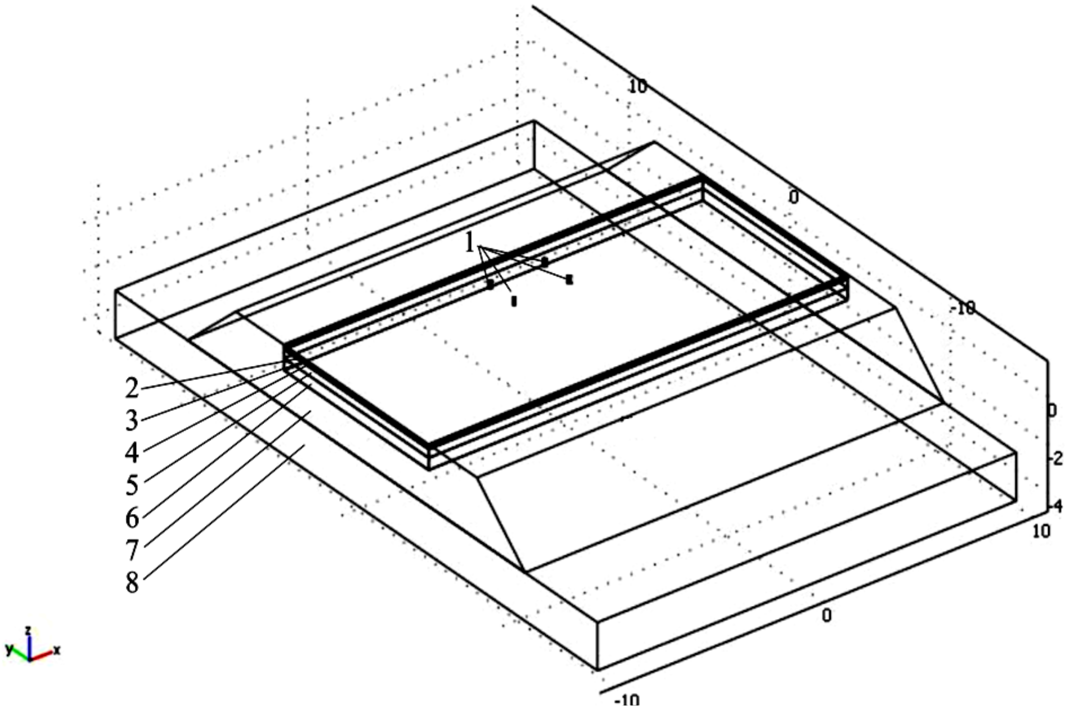

Fig. 1. Structural model of road structure:
1 — points of application of vehicle tyres; 2 —upper layer of surface; 3 —bottom layer of surface; 4 —upper layer of base; 5 —bottom layer of base; 6 — sand underlying layer; 7 — floor oil; 8 — natural soil

Table 1

Characteristics of materials used to construct the structural model

Layer number	Structure layer	Layer thickness h, cm	Layer modulus of elasticity E, MPa	Density, kg/m^3	μ
1	Fine-grained dense asphalt concrete of type A of grade I based on БНД 60/90	5	3200	2380	0.25
2	Coarse-grained porous asphalt concrete of grade I based on БНД 60/90	7	2000	2350	0.25

End of Table 1

Layer number	Structure layer	Layer thickness *h*, cm	Layer modulus of elasticity *E*, MPa	Density, kg/m^3	μ
3	Coarse-grained porous asphalt concrete of grade II based on БНД 60/90	8	2000	2350	0.25
4	Fractionated slag crushed stone M-800	36	450	2790	0.25
5	Sand underlying layer	50	100	2600	035
6	Floor oil	-	73	2610	0.35

To perform mathematical modeling of the vehicle action on road surface, design-basis characteristics of vehicles equivalent to motor car, to truck with design and off-design axle load were used (see Table 2).

Table 2

Characteristics of the vehicles

Vehicle	Load in the area of the contact of wheel with the road surface, MPa	Area of design print of the wheel, m	Radius of the print, m	Wheel-base, m	Distance between axis wheels, m
1. Mitsubishi Lancer	0.17	0.025	0.09	2.63	1.53
2. Dump truck МАЗ-555 102-220	0.6	0.1	0.18	3.30	2.20
3. Dump truck МАЗ-555 102-220	0.78	0.12	0.195	3.30	2.20

The consideration of potential forces required to calculate the deformation of road surface is performed at static action of the vehicles on the road structure. In doing so, it is expedient to use the following configurations of the transport flow:

1. Single motor vehicle;

2. Single vehicle with design load;

3. Single vehicle with load exceeding design value;

4. Traffic lane filled with motor cars;

5. Traffic lane filled with cars with design load;

6. Two traffic lines filled with cars with design load.

The design is performed by the finite element method in the form of displacement method. The choice of this method is explained by the simplicity of the algorithm and by physical interpretation of the processes under deformation of the road structure, and the use of modern mathematical software package Matlab and Comsol simplifies the account of boundary conditions of complex geometry. The assumed equations are deflection equation of the slab which lies on the elastic base in the form of elastic half-space under the action of transport load.

The displacements of each point of the road structure and stresses brought about in structure layers by transport action were obtained. Fig. 2 shows the value of deflection of II class road surface. The length of the road is 20 m. The vehicle is placed through the centre of design site where deflection value is calculated along the right line of the track.

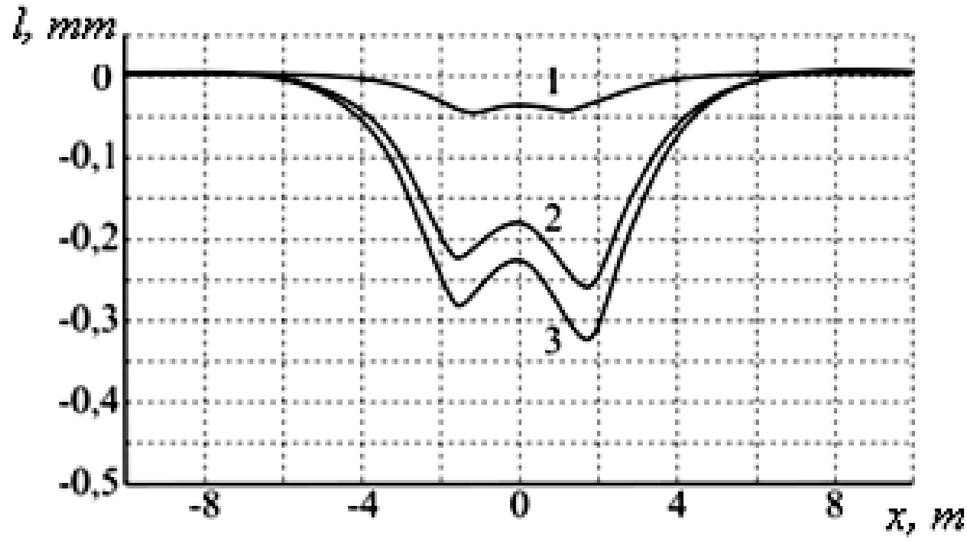

Fig. 2. Surface deflection under the action of single vehicles:
1 —motor car;
2 — vehicle with design load;
3 — vehicle with load exceeding the design load

The value of surface deflection under the action of a single motor vehicle is equal to 0.045 mm, while value of surface deflection under the action of a single vehicle with design load is equal to 0.26 mm, which 5 times exceeds specified value. 1.25 times increase in load on axis results in increase in deflection up to 0.32 mm. The given case corresponds to the action of the single vehicle with the load exceeding design value on road surface.

The result obtained can be interpreted as more intensive action of vehicles having larger load on axis. This action leads to increasing elastic deflection in the areas of the contact of wheels and surface. The excess of the load over design load raises the deflection by 22 %, which results in premature road destruction and wear of the upper layer of surface, while light vehicle give rise to surface wear.

The impact of vehicles in transport flow makes itself evident in increasing road deflection (see Fig. 3). The length of simulated site corresponds to the structural model. The vehicles are placed uniformly over traffic lanes.

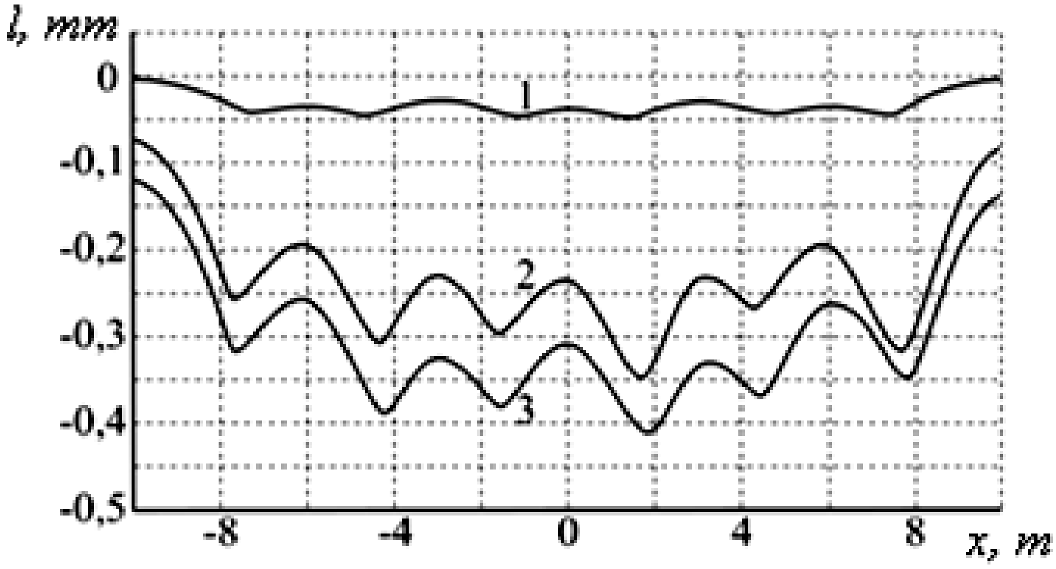

Fig. 3. Surface deflection under the action transport flow:
1 — traffic lane filled with motor cars;
2 — traffic lane filled with cars with design load;
3 — both traffic lines filled with cars with design load

The impact of transport flow on deflection differs from the impact of single vehicles. The surface deflection under the action of single vehicles in flow is 0.049 mm, which is close to the value of deflection under the action of a single vehicle.

The effect of car flow with design load on surface deflection is manifested in increase in deflection up to 0.35 мм, which is equivalent to its increase by 35 % from initial value. The movement of vehicles with design load in two traffic lanes results in 58 % increase in deflection compared to a single vehicle with design load.

Moving vehicle exerts physical action on surface by means of wheels. The higher the mass of vehicle, the larger the road deflection whose value depends on depends on design and strength properties of the road structure.

Conclusions. Conducted numerical modeling of transport flow effect on road structure revealed the increase in surface deflection compared to a single vehicle. The value of deflection under the action a single vehicle with design load 5 times exceeds the value of deflection under the action of a motor car. 1.25 times increase in load on axis results in equivalent increase in deflection.

The mathematical model of formation of road surface deformation under the action of different configurations of transport flow confirmed the fact that overlap of deflection bowls of road structure results in increasing elastic deformation. Deflection bowl radius depends on vehicle mass and mechanical properties of the road.

The deflection under the action of motor vehicles in the flow approaches the value of deflection under the action of a single vehicle, which is indicative of little influence of mechanical properties of roadbase.

The influence of car flow with design load on surface deformation with deflection bowl overlap manifests itself as non-linear increase in maximum values, which may results in residual deformations of road surface and roadbase. The excess of a transport load over design one results in premature road destruction and premature wear of the upper layer of road surface.

The revelation of relationship between road deformation and action of transport flow will make it possible to determine operation conditions of road surface and to recommend measures on road site repair and reconstruction.

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