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VIBRATING DESTRUCTION OF FLEXIBLE PAVEMENT AND A WAYS OF INCREASE OF THEIR DURABILITY

Abstract

In the article the new concept of the reasons of premature destruction of the flexible pavement, based on additional deformation vibrating loading is revealed. The mathematical model of formation of layers of the pavement ensuring reduction in vibrating loading for increase of serviceability and durability of pavement is presented.

Keywords: durability, pavement

The most objective indicator of the presence of unresolved problems in road building is premature destruction of the pavement. The basic recommendations about struggle against this phenomenon are obvious enough: hardening of the pavement and the ground base, application of the best road materials and introduction of system of preventive repairs.

However, use of these recommendations at designing, building and repair of highways leads to considerable economic expenses, but doesn't give considerable effect. It is connected to the fact that relationships of cause and effect of premature destruction of the pavements till now are insufficiently studied and scientifically investigated.

At strength analysis of flexible pavement co-ordinate planned durability of road clothes to a constant annual gain of volume of traffic. The pavement should have also necessary safety factor on loading. The factor of dynamism considering a difference between static and dynamic influence is entered into assumed loadings. Calculations are made for the most dangerous period of operation when the soil of subgrade possesses the minimum strength.

As a result, the pavement designed on the basis of all complex of calculations, should have theoretically sufficient safety factors. It is also necessary to take into consideration that real deformations of layers of the pavement, formed at movement of lorries, are insignificant on size.

The statistical analysis of materials of inspection of pavements in Russia shows that on the average by fifth year of operation of highways in the Russian Federation the majority of road surface have already an unsatisfactory condition. Residual deformations to this period is almost imperceptible. If not to make corresponding road rehabilitation the road surface will intensively continue to be destructed further with simultaneous growth of residual strain. If not to make preventive repairs after some initial stage of operation of a highway, process of avalanche increase of destructions with simultaneous growth of residual deformations begins.

It is necessary to explain premature destruction of pavements the road-traffic, is constructive-technological, climatic and other reasons. For example, it is considered that the raised destroying ability multiaxial trucks is connected with presence on them the raised design axial load. Specify also in growth last years speeds of movement. Without denying these facts, we will notice that deflections of pavement at operation heavy-load multiaxial trucks do not exceed 0.5 mm, i.e. they much less the maximum-permissible.

The Russian and American researchers have experimentally established size of curvature and the size of a deflection under a wheel which depend on bearing capacity of an asphalt concrete pavement and speed of movement of the car (Fig. 1). At increase of speed of movement to certain size, deflections decrease proportionally to speeds. Then they almost keep invariable level. So at V = 40 km/h, the maximum local deflection of a surface asphalt concrete pavement under a wheel of the moving truck makes 0.14 mm, and at V = 80 km/h – only 0.07 mm.

To the principal causes causing local defection surface destruction of an asphalt concrete pavement, referred also are the use of poor-quality basic materials, poor-quality production asphalt concrete mix, overdose of bitumen, a stop in the process of work paver, poor-quality and insufficient consolidation of an subgrade and bearing layers of the road base, small strength of an subgrade, etc.

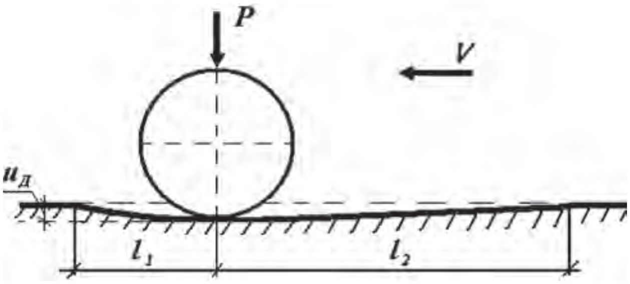

Fig. 1. The scheme of a bowl of a deflection of a pavement: $u_Д$ – deflection of a pavement.

It is natural that timely elimination of destruction of layers pavement and a soil of an subgrade essentially increases highway service life of highway structures. Preventive procedures for the road surface maintenance increase the between-repairs periods and reduce expenses for pavement repair.

For increase in highway service life of road surface the technology of building of protective coating is widely used. These layers isolate a road surface from weather and climatic effects, create a road carpet, in case of need increasing roughness.

However, all these procedures cannot solve the main task – stability of consumer properties of road (surface smoothness, strength and pavement roughness) within planned years of maintenance, taking into account growth of traffic volume, load capacity of cars and changes of their constructional characteristics.

All these actions are expensive, and the increase in durability of road designs thus slightly, therefore, an economic component of road-building projects becomes important enough. Occurrence of various modes of transferring of a part of expenses on the consumer is connected with it. For example, introduction of toll roads, tax introduction on multiaxial lorries, etc. Thus, methods and modes of increase of durability of highways, should be not only effective, but also economically expedient.

Considering as a whole process of premature destruction of the pavements, we come to a conclusion that in maintenance pavements are exposed to continuous influence from environment and moving motor vehicles. At the expense of it there is a consecutive slackening or drop durability qualities of road constructions. This reduction in strength is carried out first of all of cracks in an asphalt concrete pavement, wear grains in untied layers of the base and formation of residual deformations in an subgrade. Thus, it is not considered that one of the gear of slackening or reduction of strength of a road constructions is vibration of all its elements.

Vibration of layers of the pavement and ground of subgrade of flexible pavement arise and are supported in a current of some time because all these elements of a constructions possess inertial (weights), elastic and dissipation properties (Fig. 2). At influence of wheels of the cars expressed in the form of compression and a bend of flexible pavement, or at the expense of shock interaction with roughness on a surface of a pavement, weights of layers start moving. Full set of necessary conditions for realization of vibration process – kinetic energy of moving weights, potential energy of the deformed elastic environment and force of an internal friction in the layers, dissipating vibration energy further functions.

If vibration of motor transport well-known enough is also studied, vibration of the pavement are till now a theme of scientific debates. It is caused first of all by that this vibration can't be observed visually in connection with their very small amplitudes. They are fixed by means of special vibroizmernitelnaya equipments. Thus, the experts of road building denying presence of vibration of layers of pavement, forgetting that the basic physical parameter of an estimation of strength of a road constructions, namely, its deflection under the car, is very small and is fixed only by devices.

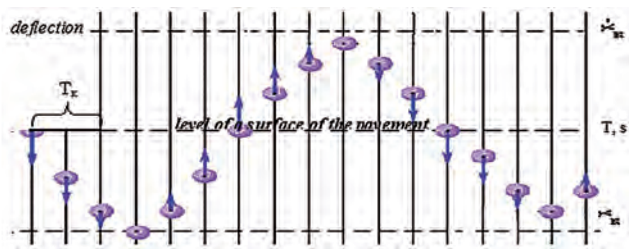

Fig. 2. The scheme of process formation of the pavement from a wheel of the moving car and occurrence of free oscillations of the pavement

The executed calculations have shown that deflections of pavements under a wheel of the moving car and dynamic vibration deflections are close on the level. During time destructive ability of vibration considerably exceeds possibilities from automobile loading.

The natural researches spent last years on highways have allowed to establish that in connection with short loading of the moving car in an installation site accelerometers, recording the vibrational spectrum of road construction, vibration layers of pavement and subgrade has a number of specific features.

Car vibration makes the minimum impact on the qualitative characteristic of vibration of a road construction and, therefore, the moving car – it is possible to consider only as the activator of vibration of the pavement layers. Excitation of vibration is thus carried out at the expense of with impact-pulse interaction of a moving wheel with a surface of a pavement. Level of the energy coming from the activator depends on speed of movement of the car, diameter of wheels and heights of road roughness.

The geometry of contact surfaces of wheels and roughness on a pavement is that the basic part of energy at their interaction come in a vertical plane. Deterioration of flatness of an asphalt concrete pavement, an event while in service, increases energy directed on excitation of vibrations and raises destructive ability of vibration.

The vibration of a road construction arising under a wheel of the car, covers some limited area of the zone, which in process of car movement moves together with it along road.

Feature of the pavement consists that in it vertical vibration can develop only and simultaneously be formed processes of transfer of these vibration on territories adjoining to a highway. The transfer of vibration representing wave process in a horizontal plane, is carried out in a longitudinal and cross-section direction of the roadway. This wave process possesses a much higher speed than speed of movement of the car. Therefore, spreading of vibration is fixed accelerometers before the car's approach to the installation site of sensors.

As the frequency spectrum of wave process partially repeats an vibration spectrum it sometimes leads to error that vibration of the pavement can be analyzed on a wave spectrum. Actually, at spreading of vibration of the pavement, there is an attenuation or absorption of some frequency components of the general vibrating spectrum, and also decrease in amplitudes of vibration.

Results of dynamic tests have shown that at car movement in section of a highway structures where it is installed acceleration gauge (Fig. 3). At approach of the car the gauge fixes the first spectrum which is characterised by very small amplitudes. At passage by wheels of the car of an installation site of the gauge, the second spectrum with maximum amplitudes in very small time interval (0.10 … 0.15 s) is realised. The size of this interval is proportional to speed of movement of the car. With increasing speed the time interval decreases. After that the third multifrequency spectrum with the big amplitudes and rather long attenuation of oscillatory process (to 4 s) is formed. The frequency structure of this spectrum does not depend on speed of movement and vehicle type as it is a spectrum of free relaxation oscillations of layers pavement.

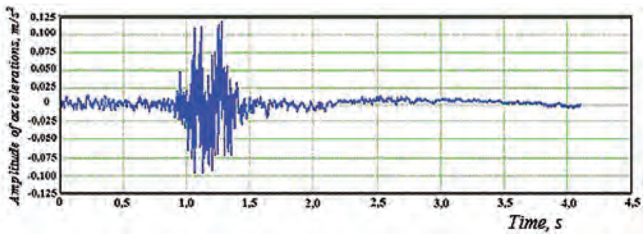

Fig. 3. The peak-time characteristic of the response of the pavement at movement of car MAZ-511 with a speed of 80 km/h [3]

Theoretically calculations established that the first spectrum representing an elastic deformation wave of vibration in a horizontal plane, cannot, because of very small vertical amplitudes, influence the process destruction of pavement.

The second spectrum reveals a physical picture process of excitation of free oscillations of layers of pavement, by means of pulse interaction of a moving wheel and road roughness of any kind. In connection with its small time of interactions of a wheel with road roughness in a zone of investigated section of the pavement and big sluggishness weights of elements of a highway structures, deformation deflections formed here depend on loading on an axis of the moving car, speed of its movement and bearing ability of pavement. These deflections are deflections resulting loading from a car wheel. Therefore, destructive ability of the given spectrum actually completely takes into account at design of pavement and calculation strength characteristics of pavement.

Presence of a long third spectrum means that the basic vibrating process in layers of pavement is free relaxation oscillations with high enough deformation level comparable to deformation indicators of the second spectrum or influence of the moving car on a highway structures.

From here the obvious conclusion follows that in connection with absence, at strength analysis, the account of vibration of the pavement (arising at movement of cars), designed strength indicators of highway structures below necessary, that is one of principal causes of untimely destruction of layers of pavement in operation.

It is necessary to consider also that deformations of layers of pavement, carried out at loading from a car wheel, and the vibrating deformations having close levels of pressure, from the point of view of destructive ability, aren't equivalent. It is connected by that deformation processes are formed in the various ways loading. At influence of a wheel of a vehicle, layers of pavement are exposed loading a kind «downloads – unload» (Fig. 4a). At oscillations loading has sign-variable power character (Fig. 4b). Qualitative distinction of this loading is presented in Fig. 4.

At sign-variable deformations the objects possessing limited flexibility which concern of an asphalt concrete pavement, at such deformations quickly enough lose the bearing capacity and destruction by means of formation of cracks. Therefore, at strength calculations, having such deformations, it is necessary to enter the admissible pressure lowered on 50–70 % that isn't carried out because of absence of the account vibrating loading.

Long-term monitoring over destruction processes an asphalt concrete pavement and numerous laboratory researches have revealed that more crack resistance an asphalt concrete of the raised flexibility possesses. Now the pavement with such asphalt concrete find universal application. However, physical essence of the improved qualities of flexible pavement till now in any way does not connect with presence of sign-variable deformations or vibrating loading.

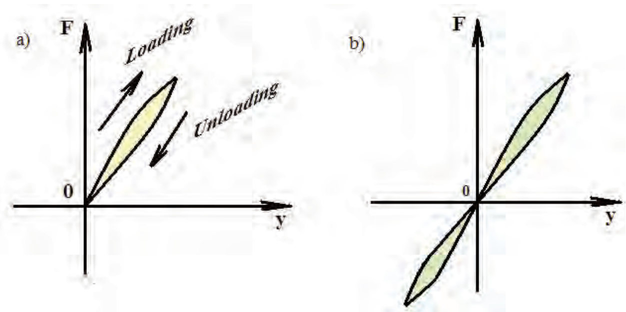

Fig. 4. The deformation characteristics of loading of highway structures, *F* – force of elastic deformation; *y* – deflection of a pavement

For the theory and practice of designing of pavement acceptance of basic idea it should be important that if the car in the course of all movement is exposed continuous vibrating loading as it constantly interaction with roughness of a road surface each section of a pavement has only short-term influence from outside car wheels. Consequently, at modelling at investigations of vibrating destruction of highway structures there is no necessity to consider system "the car – a highway structures", as uniform dynamic as oscillations of layers of pavement are made in the absence of disturbance from outside the car.

Whereas these ideas allow not only to establish the reasons of untimely destruction of layers of pavements, but also to find ways of increase of pavement serviceability and durability of highway structures.

The executed theoretical investigations and statistical materials of monitoring of highways specify in that traditional modes of increase in strength of flexible pavements do not prevent them from vibrating destruction. More often the direct increase in thickness of the pavements, conducting to growth strength indicators, on crack resistance lead to return result.

Vibrating loading of flexible pavements, according to instrument experimental base, it is estimated on level vertical vibroaccelerations more often. By means of system of filters and integration programs it is possible to express vibration level through vibration speed and vibrodisplacement. However, for use in strength calculations all these dynamic indicators aren't suitable. At designing of pavements it is necessary to pass to strength to an indicator, namely, to a dynamic deflection. Such indicator is defined by a settlement way and can be corrected by comparison to materials of natural experiment.

At passage by the car of investigated section of a pavements to it such quantity of deflections of loading from the car which is equal to number of axes of the car is realized. At excitation of vibration the number of oscillatory deflections is defined by a frequency spectrum of joint oscillatory of layers of pavement. As an important indicator is not only presence of deflections, but also their sizes, it is necessary to consider peak levels as well. Amplitude of vibrating deflections there are less than amplitudes of deflections loading from the car, but they in an initial range of damped oscillations have close quantity. On the deformation indicator they can be simulated as deflections loading from cars with smaller loadings on an axis, than at the car – the activator of vibration.

Thus, vibrating loading it is possible to transform to model loading a pavements movement of numerous cars with the lowered loadings on an axis. At such modeling by the basic destructive factor the deflection quantity, and quantity or repeatability (frequency) of deflections acts not.

At growth of repeatability of deflections the number additional loading which are received by a highway structures while in maintenance.

Repeatability or frequency deflection a spectrum and peak level of deflections completely depends on a pavements or physical parameters of layers of pavement. The major influence on a deflection spectrum has parities of the partial frequencies of all vibrational system, which is represented by multilayered pavement. In turn these frequencies are formed by parities of weights and elasticity layers.

At a rational parity of physical parameters of layers in a pavement, in the course of joint oscillations of its elements, the frequency spectrum of deflections with the lowered amplitudes and small repeatability will be realized. At other parity the reverse effect turns out. Unfortunately, unsuccessful parities have the majority of operated pavement. Therefore their durability is supported only limited time by means of preventive repairs.

As an example in Figure 5 expected dynamic deflections generated in the course of oscillations of two variants of the same of highway structures are presented.

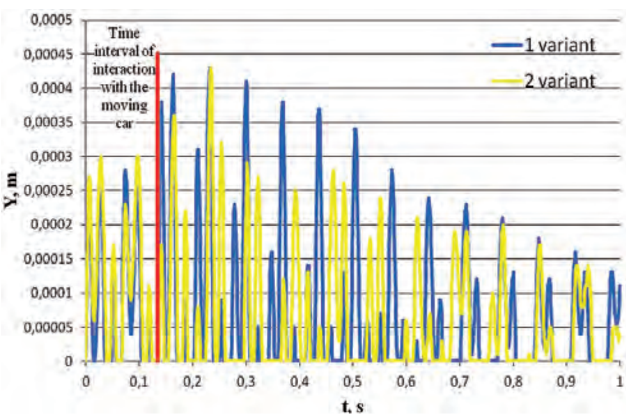

Fig. 5. The Progibno-time dynamic characteristic of highway structures

The highway structures represents the five-layer: dense asphalt concrete, porous asphalt concrete, bitumen macadam, graded crushed stone and sand. Distinction by variants consists of different thickness of asphalt concrete pavement layers. In the first variant the thickness of a layer dense asphalt concrete makes 0.04 m and porous asphalt concrete 0.15 m, and in the second variant of 0.05 and 0.13 m accordingly. Thickness of layers in the road base and a layer of sand are identical, making the total thickness 0.48 m. The basic indicator characterizing strength of a pavement, it is considered to be the elasticity module. The settlement module of the elasticity, the presented first variant of a pavement, makes 448 MPa, and the second – 384 MPa.

From Figure 5 follows that a background vibration on amplitudes of dynamic deflections a little above at the first variant. The raised repeatability of amplitudes on the presented time interval is ascertained at it also. We will notice that at first sight the difference of dynamic indicators (level of amplitudes and their repeatability) on variants is insignificant. However, it is necessary to take into account that it is indicators vibrating loading, one car generated after travel. At long-term operation of the pavement, the presented distinctions become determining.

If vibrating loading to present as additional number of application of load from the design vehicle at planned pavement service life in 15 years the actual number of application of load in the first variant will be increased in 2.2 times in comparison with the second variant. As a result, planned working life of pavement taking into account the vibrating factor will make 2.2 and 5.4 years by variants accordingly. These terms are close to average indicators for operational highways in Russia.

Having established that level and the form of vibration of a pavement depend on some parity partial frequencies of layers of pavement or selection of their weights and elasticity, it is possible to pass to purposeful formation of pavements which will have lowered vibrating loading.

Such approach to consideration of physical processes of interference of oscillation layers of pavement has made possible to develop a method of design of pavement taking into account the vibrating factor, based on a basis of realization of a rational parity partial frequencies or frequencies of elastic communication of layers.

This correlation can be expressed two polynomial dependences of calculation of rational selection of thickness of layers and them stiffness parametres:

$$h_i = (a_1 i^4 + a_2 i^3 + a_3 i^2 + a_4 i + a_5)\frac{\rho_1}{\rho_i} * h_1, \text{ m} \quad (1)$$

$$c_i = (b_1 i^4 + b_2 i^3 + b_3 i^2 + b_4 i + b_5)\frac{\rho_1}{\rho_i} * h_1 * E_i * 10^3 \text{ kN/m} \quad (2)$$

where: h_1 – thickness of the first layer of pavement, m; h_i – thickness of i-th layer of pavement, m; c_i – stiffness of i-th layer of pavement, kN/m; ρ_i – bulk density of a material of i-th layer of pavement, kg/m^3; E_i – the module of elasticity of i-th layer, kN/m^2; i – serial number of a layer of pavement.

The coefficients of polynomials ai, bi are calculated for a specific construction of pavement.

As it was marked a rational correlation of frequencies of elastic communication of layers of pavement repeatability and size of amplitudes of dynamic deflections decrease. It is visible in Figure 6 for which the pavement with lowered vibrating loading is simulated and is presented as a variant 3. In comparison with the second variant repeatability at a variant 3 more than twice is less.

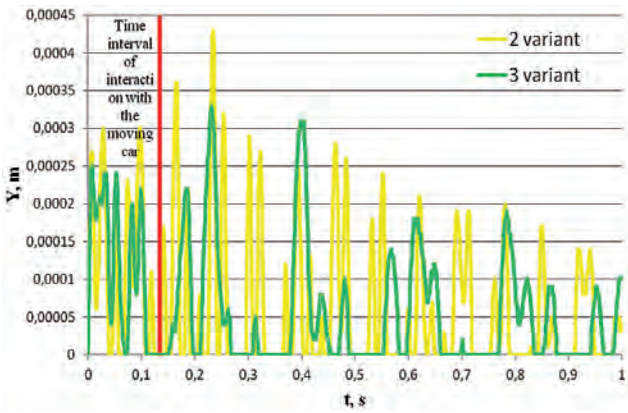

Fig. 6. The Progibno-time dynamic characteristic of highway structures

Physical and strength indicators of variant 3 make – the module of elasticity 352 MPa, a thickness of a layer dense asphalt concrete 0.05 m (as at variant 2), a thickness of a layer porous asphalt concrete 0.07 m (twice it is less than at variant 2), a correlation of thickness road base of road metal and sand is picked up according to polynomial dependences (1) and (2), the total thickness of pavement is almost identical. The basic increase in thickness was made on a sand layer.

For the third variant the vibrating additional number of application of load in 1.8 times is less than at variant 2 and planned working life makes 11 years. It is obvious also that it is economically more favourable variant of pavement.

Designing of pavement taking into account the vibrating factor, based on an rational correlation of frequencies of elastic communication of layers, may allow to finish operational life to planned terms and it is essential to lower expenses for building of highways and for all kinds of repair.

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