The problem of mechanical loads on pavement of roads in the cryolithic zone

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Abstract. By a process of field studies of roads in the cryolithic zone the main types of defects and destructions of asphalt concrete pavements related to mechanical load from vehicle wheels were identified. The dominant types of deformations that form in warm and cold seasons of the year, as well as factors causing them, were determined. It was found that, regardless of the temperature in any arbitrary transverse road profile, the load on the traffic rut from the car wheel has an impulse character. The frequency of the impulse action depends on the speed of the vehicle, the number of axles and the distance between the axles. The amplitude of impulses depends on the weight of the vehicle and the evenness of the pavement.The unsuitability of regulatory documentation on load calculation for practical application was proved.

1 Introduction

In recent years, much attention has been paid to the quality of roads in the road construction industry of the Russian Federation. At the same time, the quality of road is a synergistic effect of the response of various structural materials of roads to traffic loads in specific natural and climatic conditions. The load on the road should be taken in the broadest sense. A moving car affects the road not only due to its weight. Being a complex technical system, it affects the road due to mechanical vibrations, as well as a wide range of wave, including sound, and electromagnetic vibrations. These impacts are especially important in studying the stability of construction materials of roads in the cryolithic zone, which are characterized by a high water content in summer and a significant amount of ice in winter period.

2 Literature review

Studies of the state of asphalt concrete pavements and subgrade soils of roads in the cryolithic zone, unfortunately, are not systematic. This is due, first of all, to the natural and climatic features of the territories where permafrost develops. For example, in Central Yakutia, the average annual air temperature according to various open sources is minus 9-10 degrees Celsius. At the same time, in the area of the city of Yakutsk, the annual summer temperature maxima reach 43-45°C, and the winter minimums reach minus 60°C. Accordingly, both in

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winter and summer, there are significant difficulties even in instrumental studies, for example, of physical and mechanical properties of asphalt concrete pavements. In summer, due to the intensive absorption of solar radiation, asphalt concretes become too plastic and the elastic moduli of the surface layer are practically almost zero. In winter, full-scale measurements of the elasticity modulus of asphalt concrete are possible only up to a temperature of approximately minus 20°C [1], and at lower temperatures, the existing instrumental and measuring base is not able to work. Moreover, at extremely low temperatures around minus 50 ° C, the measuring equipment most often goes out of service.

In general, the problems of physical and mechanical properties and engineering-geological processes in soils of an earthen embankment, as well as the issues of the behavior of pavement materials at low temperatures of roads in the cryolithic zone, were generally discussed in a number of works, for example [1-14]. Nevertheless, the analysis of the scarce scientific literature on the sustainability of roads of cryolithic zone reveals several characteristic features. For the purposes of this publication, the most important are:

1. Most of the publications are related to the results of scientific research conducted during the spring-autumn seasons, when the temperature of the structural elements of roads does not fall below minus 1°C [6-11].

2. There is an obvious binding of scientific publications to a certain temperature regime. Studies are carried out in two temperature ranges, the boundary between which is located within 0 - (-)1oC.

3. None of the papers discusses the main factor that has the maximum impact on all processes taking place in the structural elements of roads, regardless of the season and temperature. This dominant factor is the load on the road structure from the wheels of vehicles.

The first two features demonstrate that the roads in the cryolithic zone operate in two fundamentally different modes - summer and winter. Moreover, the stability of roads in these operation modes is controlled by completely different environmental factors. The only all-season factor is just the traffic load on the road. At the same time, it seems obvious that the form of the physical impact of the load factor on the pavement will be very different in summer and winter. This is due, first of all, to significant differences in the state of road construction materials at negative and positive temperatures.

3 Literature review

The fundamental regulatory document for load calculation in road construction industry is GOST R 52748-2007 “National standard. Automobile roads for general use. Standard loads, design loading schemes". However, this document, as well as all others, does not take into account the form factor of the impact on the road load at different temperatures and different seasons of the year. At the same time, rather controversial principles, often contradicting reality and physical laws, are laid down in the basic regulatory provisions and the designated parameters. Some negative features of the regulatory document under discussion have already been considered [15]. In this paper, it is necessary to consider this document in more detail.

The model of a passenger car (model trolley) adopted in the State standard, on the basis of which all calculations are carried out, is shown in Figure 1. Legend for Figure 1: K – load class. It is measured in kilonewtons (kN). Depending on the road category, it can vary from 6 to 11.5. For the vast majority of roads in the cryolithic zone of regional and federal significance K = 10 kN; d – base for the load. Measured in meters; c – load track width, m; q - equally distributed load along the road (building), kN/m.

Model trolley dimensions are given in meters.

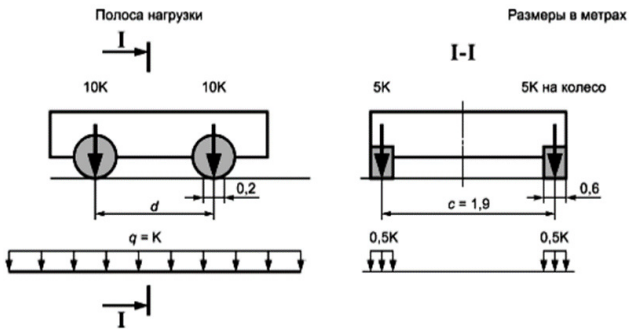

Fig. 1. Scheme of distribution of loads on the roadbed from a model trolley/passenger car. Given according to GOST P 52748-2007.

First of all, it is necessary to pay attention to the width of the wheel of a standard passenger car. According to Figure 1, it is 60 cm. The author is not aware of mass-produced passenger car models with such tires.

The scientific and practical inconsistency of the parameters for calculation of load on structural elements of roads is proved by the introduction of the indicator of “equally distributed load along the road” (q) into the regulatory documentation. For example, according to Figure 1, it is equal to the load class (K). In this case, an equally distributed load has the unit of measurement- kN/m, and the load class - kN. On the other hand, the load from the wheel on the pavement from a stationary car, due to physical laws, cannot be distributed equally “along the road”. The load has a volumetric (areal) distribution, causing the occurrence of normal (compressive) stresses (σ) in the road soil massif. The calculation of σ for any point of the soil and the construction of stress diagram for a car is carried out either according to the Boussinesq formula, or within the framework of solving the plane Flaman problem. Detailed calculation methods are presented in any textbook or manual on the discipline of "Soil Mechanics". Ignoring the well-known physical laws by the authors of the normative document, apparently, led to the appearance of other unfounded constructions. Thus, a model passenger car, judging by Figure 1, with free fall acceleration g=9.8 m/s2 has a weight of more than 20.4 tons, and each wheel exerts a load equal to 510 kg on the road surface, i.e. the total impact of the four wheels will be only 2.04 tons.

In the regulatory document, newton is chosen as the unit of measurement for load. This is very useful for comparing road load measurement data from different regions. Moreover, the entire instrumental measuring base automatically provides data on the load in newtons. However, in practice, when verifying data with other characteristics of vehicles and calculating the design of roads, practical insoluble problems arise:

1. Newton is a unit of force measurement. When making calculations for real cars, for which only the weight is known, it is necessary to know the exact numerical value of the free-fall acceleration (g), which has an individual value at each point on the soil surface.

2. Axial pressure, expressed in newtons, is not related to the load exerted by the vehicle on the road. It shows the force with which the car (or its part) presses on the stem of the measuring tool. At the same time, instrumental measurements of the axle load are a rather complicated procedure and can only be carried out for a stationary vehicle.

3. The load on the road from a vehicle can be expressed in newtons, pascals and as a weight. When solving production problems, the newton is inconvenient due to the lack of exact values for free-fall acceleration. In the case of Pascal, the same problem is further compounded by the need of obtaining data on the contact area of the car tires with the road, because 1Pa=1N/S (N/m2), where S is the contact area. In real conditions, the contact area depends on many factors, such as vehicle type, tire diameter, type and width, manufacturer,

material properties and construction of the tire/wheel, pressure level in the tire/tube, ambient temperature, etc. Accordingly, it is not possible to measure the area of contact of all wheels of each car in the traffic flow. Therefore, the only objective and functional parameter that can be used for practical load calculations is the car weight. Taking into account the regulatory requirements for the reliability of road structures, the car weight should be determined at its maximum load.

4 Description of the research

As multi-year observations show, there are two periods clearly distinguished according to the nature of impact of the load from vehicles on the roadway, delimited by an air temperature of 0 ° C. Accordingly, periods of positive and negative temperatures are distinguished. When the temperature passes through 0°C in spring and autumn, deformations and destruction of road structural elements occur due to changes in the specific volume during the water-ice phase transition [5,7,9]. According to the author, this process appears and intensifies only in presence of a road surface already broken by cracks or a violation of road construction technologies, which lead to a sharp increase in moisture in the base soils of the pavement. The heaving process has a pronounced secondary character and, therefore, is excluded from consideration in the framework of this paper.

Period of positive temperature. During this period in Central Yakutia, especially in summer, asphalt concrete pavements can be heated up to 60 ° C or more by the sun rays. At such a temperature, asphalt concretes pass into a viscous-plastic state, their modulus of elasticity [1] decreases. On the other hand, at high temperatures, intensive thawing of soils of the pavement base begins, represented mainly by clay sand and loam. The thawing depth can reach 4 meters, with an average value of 2-2.5 m. Ice melting leads to an increase in the moisture content of earth embankment, and the reduced moisture conductivity of clay rocks [6,8,10,11] prevents the removal of water from the earthen embankment. The moisture content of asphalt concrete base soils can be so high that on certain sections of roads in the cryolithic zone, specific destruction/separation cracks are formed, forming structures similar to landslides (Fig. 2) in asphalt concrete pavements, under the influence of gravity and/or shear deformations from the wheels of moving cars.

Fig. 2. Destruction of the asphalt concrete pavement in the rut due to shear loads with extrusion of soil onto the surface of pavement on the Nam Regional Road. Photo by Ediseev O.S.

High temperatures of the warm period of the year provide flowing of complex engineering and geological processes in the structural elements of roads in the cryolithic zone. As a result, the road as a whole represents a rather unstable structure to external

influences (load). The main factors of structural instability are plastic asphalt concrete pavements and the underlying waterlogged subgrade soils.

Fig. 3. Numerous longitudinal cracks along the edges of the rut. Nam Regional Road, km 47. Photo by Ediseev O.S.

The deformation of road surfaces under the influence of the load from wheels of vehicles on the roads of the cryolithic zone begins with the formation of a rut. The rut is a result of the deflection of asphalt concrete pavements along the line of motion of vehicle wheels. The depth of the rut depends on the weight of passing cars, the temperature of asphalt concrete, the moisture content of base soils of the road pavement and can reach 4–5 cm. The next stage in destruction of the road pavement is the appearance of longitudinal cracks in asphalt concrete, localized on the edge of the rut (Fig. 3). Their formation is associated with a fairly rapid deepening of the rut and an excess of the tire pressure force on the pavement of the resistance force to the rupture of asphalt concrete.

At the final/critical stage of destruction, the formation of longitudinal rupture cracks in thalweg of the rut occurs. The asphalt concrete of the pavement loses its waterproofing properties, which causes a sharp increase in moisture content and, accordingly, the plasticity of soils of the pavement base due to the ingress of rain and melt water. The pavement loses its support at the base and begins to undergo intense cracking / crumbling under load (Fig. 4). When passing through 0°C, the process of pavement destruction is accelerated by the effect of heaving.

Fig. 4. Grid of cracks in rut on the regional road Umnas, km 48. Photo by Nikolaeva G.O.

The destruction of asphalt concrete pavements can also occur without the formation of rupture cracks on the edge and rupture cracks in thalweg of the rut. This also happens on the basis of temperature [3,4] cracks in cold period of the year when they cut through the entire thickness of the asphalt concrete pavement (Fig. 5). The figure serves as an indirect proof that the stability of asphalt concrete road pavements in the cryolithic zone depends on many factors. However, the construction technologies and the moisture content of construction materials are dominant.

Fig. 5. Grid of cracks on the pavement in traffic rut based on the temperature crack. Umnas regional road. Photo by Nikolaeva G.O.

It is necessary to pay special attention to the ambiguous situation with the formation of traffic ruts on roads of the cryolithic zone.

On the one hand, its formation is inevitable. The construction of roads is calculated and designed in accordance with regulatory documentation. The standard load on pavement is determined on the basis of GOST P 52748-2007 or its revised edition of later years according to the scheme shown in Figure 1. The calculated axial load (P, kg) from the model trolley on the roadway at an acceleration of free fall of 9.8 m/sec2 is 1020 kg. In real conditions, the load on the rear axle, for example, of the LiAZ 5292 bus with a full load of passengers (114 people) is 16700 kg. Thus, the estimated/design regulatory load is 16 times less than the actual one for a specific type of vehicle. At the same time, according to the pavement calculation scheme of paragraph 5.1.2 of GOST P 52748-2007 - "The axis of the standard load ... when calculating non-rigid pavements is placed in the middle of the traffic lane," i.e. the calculation is made for a road section on which there is practically no pressure from the wheels of vehicles. Accordingly, the formation of rut on the roads of the cryolithic zone is not surprising.

On the other hand, the formation of a rut on the roads is impossible based on construction technologies and deformation morphology. In the warm season, the formation of a rut is possible due to the extrusion of plastic asphalt concrete by the wheels towards the edge of the rut formed on the basis of this process. In this case, the edge will be slightly higher in marks compared to the undeformed pavement. However, field observations and measurements show that such a wavelike prominency is never observed on the edges of the rut. The rut is always formed as a failure or indentation of asphalt concrete into the base soils, i.e. a void should form under the pavement or the foundation soils should become fluid. From the standpoint of normalized methods for calculating, designing and building roads, this cannot happen. Clay sand and loam serve as soils for pavement. In accordance with the requirements of regulatory documentation, foundation soils must have a compression ratio

(Rc) in the range of 0.95-0.98 before laying asphalt concrete pavements. Considering that Rc=ρact./ρmax., where ρact. – actual soil density, ρmax. – the maximum possible density of the soil, we find that the porosity of the rocks is 2-5%. In order to form a rut with a depth of 5 cm with a rock porosity of 5%, the maximum degree of compaction should reach the earth base soil under asphalt concrete to a depth of 1 m. It is very unlikely that compaction to such a depth is possible by transferring the load from wheeled vehicles through an asphalt concrete pavement having a thickness of at least 10 cm. Moreover, with direct compaction of these soils, much heavier road-building machinery with built-in vibration mechanisms is used during construction. Consequently, the formation of a rut is associated with some kind of physical and mechanical process that takes place in the foundation soils and leads to the redistribution and removal of their substance from the rock masses under the rut.

There are only two of the known engineering and geological phenomena, which can be responsible for the formation and the most promising are suffusion and solifluction. Solifluction on the slopes of the earth embankment in the cryolithic zone is recorded constantly [6,9,11]. It is the main external sign and the end result of the denudation/destruction of the subgrade. However, the movement of material towards the slopes inside the body of the earthen embankment of the road is possible only on the basis of suffusion processes, intensified by vibrational (mechanical and wave) loads from moving vehicles. Unfortunately, based on the analysis of the regulatory framework of the road construction industry, it must be stated that suffusion processes are formally unknown to road builders and it is believed that their scientific research and monitoring are of no practical interest.

Period of negative temperature. During the period of negative temperatures, two types of cracks are formed in asphalt concrete pavements - frost or reflected and temperature ones [1,3,4]. The reasons for the formation of frost cracks are unknown, but, most likely, they are associated with the dynamics of the subgrade freezing at a decrease in temperature. Temperature cracks are the result of rupture of asphalt concrete during their compression with decreasing temperature [1,2,3].

Fig. 6. Initial stage of temperature crack formation. Photo by Gabyshev M.V.

Temperature cracks form in three stages. At the first stage, a crack appears (mainly in a new road pavement). The crack opening width does not exceed 1 cm. The depth [2] corresponds to the thickness of the upper layer of the asphalt concrete pavement (Fig. 6).

Fig. 7. The final stage of opening of the temperature crack. Photo by Gabyshev M.V.

At the second stage, when the ambient temperature decreases, the crack expands and deepens as a result of thermal compression (Fig. 7), leading to the destruction of asphalt concrete throughout its entire thickness [2].

At the third stage, the complete destruction of asphalt concrete pavements begins in the most weakened places. Most often, such weakened zones are rut sections, in which transverse temperature cracks and longitudinal fracture cracks intersect, passing along the lock of the rut deflection (Fig. 8). In summer, the process of destruction of asphalt concrete under load intensifies (Fig. 5), eventually leading, due to the process of suffusion and load, to extrusion of foundation soils onto the road surface and complete destruction of pavement (Fig. 2).

The analysis of the features of destruction of asphalt concrete pavements at negative temperatures (Fig. 8) shows that they can appear as a result of mechanical impulse action.

Fig. 8. Destruction of the open temperature crack under the influence of impulse loads from car wheels. Photo by Gabyshev M.V.

5 The pattern of the weight loads on asphalt concrete in the rut of car wheels

The complex of information obtained during many years of field studies of roads in the cryolithic zone dictates the need to identify the pattern and dynamics of changes in the mechanical load on asphalt concrete from the wheels of real vehicles and compare the results with the impact of a standard vehicle.

The calculations were carried out for a standard vehicle (Fig. 1) and two types of vehicles, one of the most common in the Republic of Sakha (Yakutia). The speed of movement of all vehicles, taken in the calculations is 60 km / h. The width of the wheel contact area with the road surface along the traffic line for all types of cars is 20 cm (Fig. 1). Main parameters of vehicles:

1. Model trolley/standard vehicle: number of axles -2, front axle - 1F, rear axle -1B, base 2.5m, single wheel weight -510kg.

2. City bus LiAZ 5292: full load - 114 passengers, axles - 2, front axle - 2F, rear axle - 2B, base - 5.0 m, weight load of one wheel of the front axle - 6.15 tons, weight load of one wheel rear axle - 8.35 tons.

3. Truck KAMAZ 65115-48: axles - 3, front axle - 3F, rear axle 1 - 3B1, base - 3.19 m, rear axle 2 - 3B2, axle distance 3B1–3B2 - 1.32 m, weight load of one wheel of the front axle - 3.1 tons, the weight load of one wheel of the rear axle - 4.75 tons.

The pattern of the distribution and the value of the weight load on the rut from one wheel of the discussed vehicles along the line of their movement (parallel to the longitudinal profile of the road) are shown in Figure 9.

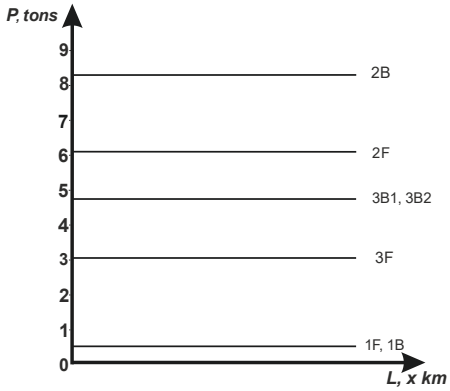

Fig. 9. The pattern of the distribution of the weight load from the wheel along the line of car motion.

As can be seen, in particular, from the figure: the maximum weight impact on asphalt concrete is exerted by low-floor city buses when fully loaded with passengers; the value of the axial load of all axles of city buses and KAMAZ vehicles exceeds the permissible load for city streets and roads (6 tons) by 2-3 times; there is no formation of the q "distributed load" diagram (Fig. 1) - along the line of motion of the car wheel, each subsequent point accounts for the entire weight load falling on this wheel when the car is moving; the principle of calculating the load on pavement based on the “passenger car unit”, laid down in the regulatory documentation, cannot be applied to calculate the stability of roads in the cryolithic zone.

The pattern and dynamics of change in the weight load from the wheel on pavement in any arbitrary transverse profile is shown in Figure 10. The calculation of the weight load data was carried out for the transverse profile with the length of the vehicle tire contact area with asphalt concrete along the driving line equal to 20 cm. Vehicle speed is 60 km /hour.

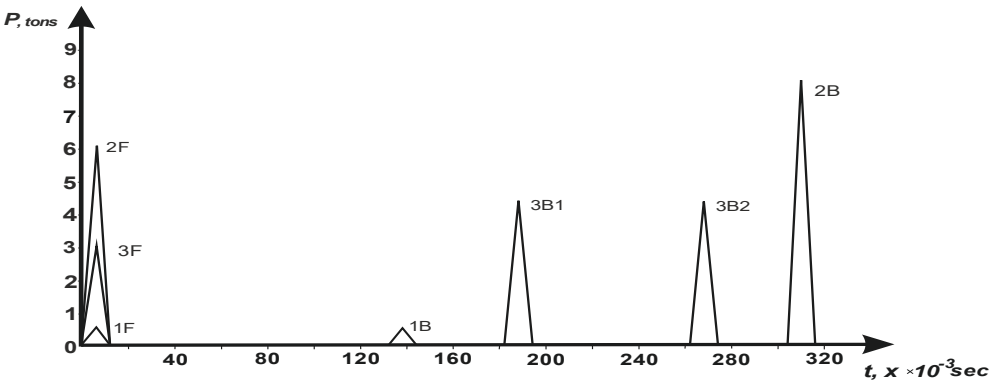

Fig. 10. The pattern and dynamics of impulse weight loads from the wheel in the transverse profile.

The transverse profile clearly shows the impulsive nature of the impact of weight load on the road. The impulse frequency depends on the speed of vehicle, the number of axles on vehicle and the distance between the axles. The real amplitude of the impulses can be adequately reflected only in kilograms. For certain purposes, for example, when linking an impulse to a point load on a transverse profile line, it is possible to represent the amplitude in pascals. In this case, the impulses will be expressed as straight lines. In the figure under discussion, the maximum amplitude corresponds to half the value of the axial pressure. It should be emphasized that the calculations were carried out for roads with perfectly even pavement. In real conditions, inequalities will provoke fluctuations in the amplitude of impact of the weight load from wheels on the track in accordance with known physical laws. For example, when a wheel contacts the pavement after it breaks off when hitting a bump or jumping to the bottom of a pothole, the impact energy will increase by the amount of the released kinetic energy. In general, even on a perfectly even road, the nature of the impact of the wheel on the road in the transverse profile is identical to the work of a stamping press.

In the warm period of the year, due to low elastic moduli, the development of asphalt concrete deformations is dominated by the "linear" type of load (Fig. 9). In the cold period, due to very high moduli of elasticity - "transverse" (Fig. 10).

6 Summary

Based on the studies of deformations of asphalt concrete pavements of roads in the cryolithic zone under the influence of a mechanical load from the car wheels, the following main conclusions can be drawn:

- During the warm period of the year, ruts form in the plastic pavement. Its formation is possible only during the passage of suffusion processes in waterlogged base soils of the asphalt concrete, initiated, first of all, by the load from vehicles (mechanical, vibrational, wave).
- At a positive air temperature, there is no linear and areal distribution of the load from the car wheels. In a rut along the line of movement of a car wheel, each subsequent point accounts for the entire weight load falling on this wheel.
- During the cold period of the year, the destruction of pavement is localized in the weakest sections of the rut, in places where it is crossed by temperature cracks. Due to the high values of the modulus of elasticity of asphalt concrete, its destruction has the form of mechanical crushing.
- Regardless of the season, the mechanical weight load from the car wheels on the rut in arbitrary transverse profiles has an impulse character. The frequency of the impulse action

depends on the speed of the vehicle and the distance between the axles. The amplitude depends on the weight of the car and the evenness of the pavement.

- The system for estimating the load on the pavement developed in the regulatory documentation is not suitable for practical calculations.

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