Features of calculation and design of pavement enduring prolonged static load

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Abstract. The main calculation in the design of pavement is the calculation of the dynamic load. Calculation of static load is recommended in some cases specified in regulatory documents. It is necessary to prove that the calculation of the static load is required for any calculations of pavement. Using the calculation of pavement as an example, it is proved that a design that can withstand dynamic load does not always withstand static load. For the first time, a recommendation is given on the need to calculate the static load for any calculation of pavement, and not only in the cases indicated in the regulatory documents. It is proved that calculations for static load must be performed for any calculations of pavement. It is noted that different regulatory documents give different parameters for the calculation; therefore, before the start of the calculation, it is recommended to decide on which regulatory documents the calculation will be made.

Keywords: pavement, static load, standard load, dynamic coefficient

1. Introduction

In the process of a car moving along the road, an interaction occurs between the wheel of the car and pavement [2]. Moreover, depending on the road conditions and driving mode, this interaction has differences associated primarily with such parameters as:

- the nature of the load that the car has on the cover;
- load application time;
- frequency of load application.

The magnitude of the load depends on the carrying capacity of the car, the number of axles and their layout and is characterized by specific pressure in the area of contact of the car wheel with the pavement [8].

The load application time depends on the speed of the car on the road. The frequency of application of the load is directly related to the intensity of road traffic and its distribution by the hours of the day [13]. These parameters are taken into account when designing and calculating pavement.

Pavements on the stretches of roads are calculated for short-term repeatedly applied (dynamic) load [10]. At the same time, quite often a single calculation for a short-term load is not enough and a check for long-term (with a loading duration of at least 10 minutes) is required. Moreover, in some cases, the calculation of pavement is carried out only for long-term (static) load [3].

According to existing norms and rules, the calculation for long-term load is the main one for calculating pavement for:
• sidewalks, pedestrian streets, park alleys, squares of cities, etc.;
• car parking in parking lots, roadside service areas, rest areas, etc.
Additionally, it is necessary to check pavement for static load when designing:
• transitional high-speed lanes and ramps at intersections at the same and different levels;
• on roadsides and stopping strips;
• at public transport stops;
• at collection points in the case of toll roads;
• at regulated intersections;
• level crossings, etc.

Figure 1. Traffic jams on the waterfront

Testing for the long-term impact of the load is especially relevant when designing streets and city roads, where there are a large number of public transport stops, there are pedestrian walkways and pedestrian streets, and intra-quarter streets and driveways are often used as temporary and sometimes permanent parking for vehicles [6]. And where the phenomenon of traffic jams is widespread, cars are idle for much more than 10 minutes.

This article discusses the features of the calculation and design of non-rigid pavement under short-term and long-term loading and the effect of static load on the structure of pavement. The aim of the study is to prove the necessity of calculating the static load in all cases without exception when designing pavements.

2. General design characteristics of the impact of the car on pavement and the procedure for calculating non-rigid pavements depending on the duration of the load

In the General case, the calculation of pavement is carried out on the load determined by regulatory documents in force in the Russian Federation [1].
The magnitude of the regular load is determined by GOST 32960-2014, GOST R 52748-2007 and SP 34.13330.2012. Depending on the category of the road and the type of coating on it (capital, lightweight, etc.), it is 115 or 110 kN per vehicle axis. When calculating pavement, the pressure of one wheel on the coating is uniformly distributed over the area of the wheel imprint ($D$). Moreover, it should be remembered that the diameters of the circles are equal to the track imprint of the wheel ($D$) in the static and dynamic positions are not equal [12]. The value of the parameter $D$ varies depending on the regulatory document.

So, according to GOST GOST R 52748-2007 in the static position $D = 0.34$ m, in the dynamic $D = 0.39$ m, regardless of the category of the road, ODM 218.046-01 recommends the following $D$ values, depending on the standard load:

- at a load of 100 kN for a fixed wheel $D = 33$ cm, for a moving wheel $D = 37$ cm;
- at a load of 110 kN for a fixed wheel $D = 34$ cm, for a moving wheel $D = 39$ cm;
- at a load of 130 kN for a fixed wheel $D = 37$ cm, for a moving wheel $D = 42$ cm.

GOST 32960-2014 does not regulate the diameter of the imprint of the wheel ($D$), but recommends the value of the pressure of the wheel on the coating ($p$): 0.8 MPa calculation of pavement of capital type; 0.6 MPa for the calculation of lightweight pavement and transitional types.

PNST 265-2018 offers the following regulatory parameters:

- The standard pressure $p$:
  - 0.8 MPa – for roads with capital pavements;
  - 0.6 MPa – for roads with lightweight and transitional pavements.

And the standard load $P_{st}$:

### Table 1. Standard loads

| Load calculation group | Standard static load $P_{st}$, kN | Pavement pressure $p$, MPa | Diameter $D_d/D_{st}$, cm |
|------------------------|----------------------------------|---------------------------|--------------------------|
| A-10                   | 100                              | 0.6                       | 37/33                    |
| A-11,5                 | 115                              | 0.8                       | 34/30                    |

Note – The numerator shows the diameter $D_d$ – for a moving wheel, in the denominator $D_{st}$ – for a fixed wheel.

In the general case, the diameters of the prints of the fixed wheel $D_{st}$ and the moving wheel. $D_d$ is determined by the following formulas:

$$D_{st} = \sqrt{\frac{40P_{st}}{\pi p}}, \quad D_d = \sqrt{k_{dyn}D_{st}},$$

where $k_{dyn}$ is the dynamic coefficient.

Thus, when designing and calculating pavements for short-term multiple loads, parameters other than those used to calculate long-term one-time loads are used. Also, the calculations of pavement for long and short-term load also differ.

Currently, there are several methods for calculating non-rigid pavement type. The most commonly used calculation is according to ODN 218.046-01 and PNST 265-2018. The calculation principles are the same in both of these documents, some calculated coefficients and individual parameters differ.

According to ODN 218.046-01 and PNST 265-2018, the calculation of the strength of non-rigid road pavements on road sections with short-term load is carried out according to the following criteria: elastic deflection, shear resistance of molded layers, resistance of monolithic layers to bending fatigue stress. In addition, if necessary, a check for frost resistance is performed.

In this case, the strength and deformation characteristics of materials and soils are used with repeated application of a load of 0.1 s duration.
Road clothes at stops and stopping lanes located on roadsides, intersections, at ramps and approaches to intersections with railroad tracks should be additionally checked for a single load lasting at least 10 minutes using static values of the calculated parameters [4].

For pavements of reinforced roadside lanes, parking lots, as well as sidewalks, pedestrian streets and squares in cities, the calculation is performed only for a single load lasting at least 10 minutes. The calculation is performed according to the condition of shear stability.

If one or several calculations for dynamic and static loads do not satisfy the required conditions, adjustments are made to the pavement design until all conditions are met [15].

3. An example of the calculation of pavement for short and long loads

We shall consider the features of the calculation and design of pavement for short and long-term loading and shall also analyze the effect of static load on the structure of pavement. As an example, we take the calculation of pavement for a highway of the second category in the Krasnodar Territory. We will calculate according to PNST 265-2018.

![Road surface elements](image)

**Figure 2.** Road surface elements

Initial data for the calculation of pavement
Design area – Krasnodar Territory;
Category of the projected road – II;
Road climatic zone – IV;
Type of terrain for humidification – 1;
The specified reliability – \( K_r = 0.95 \) (by agreement with the customer);
Type of pavement – capital;
Soil of a working layer of a subgrade – Soil heavy loam;
Groundwater level, counting from the bottom of the pavement – 10 m;
Subgrade compaction coefficient \( K_{com} = 1.01 \) – 0.98.
Determination of the total estimated number of applications of the estimated load for the service life.
Estimated load – A11.5 (at \( P = 0.8 \) MPa);
The service life of pavement, years – 12;

Design Load Parameters:
Wheel load \( Q = 57.5 \) kN;
Tire pressure \( P = 0.8 \) MPa;
Diameter of wheel imprint \( D_d = 34 \) cm;
Diameter of wheel imprint from static loading \( D_{st} = 30 \) cm.
The total estimated number of load applications is set initially and is 91964 aW.

The estimated shear characteristics (elastic modulus and shear characteristics) of soil and sand are shown in table 2:

| Layer material                          | E, MPa | Angle of internal friction, degrees | Angle of internal friction (static), degrees | Coupling, MPa | Coupling (static), MPa |
|----------------------------------------|--------|-------------------------------------|-----------------------------------------------|---------------|------------------------|
| Sand of medium grain with a dusty clay fraction of 0 % | 120    | 28.1786                             | 32                                            | 0.003         | 0.004                  |
| Heavy loamy soil                       | 46.8554| 7.7126                              | 19.9518                                       | 0.0098        | 0.0223                 |

The calculated characteristics of the layers of pavement are shown in table 3:

| Layer material                          | Thickness, cm | Elastic modulus of elastic deflection, MPa | Shear modulus, MPa | Bending modulus, MPa | Bending tensile strength \( R_0 \), MPa | \( m \) | \( \alpha \) |
|----------------------------------------|---------------|---------------------------------------------|--------------------|----------------------|----------------------------------------|-------|---------|
| Dense asphalt concrete type B with added bitumen 90/130 | 5             | 2400                                        | 550                | 3600                 | 9.5                                    | 5     | 6.3     |
| Porous asphalt concrete with sand with added bitumen 90/130 | 7             | 1400                                        | 380                | 2200                 | 7.8                                    | 4     | 7.6     |
| Crushed stone, easily compacted (40–80 mm) with added fractionated finely crushed stone Sand and slag gravel mix from inactive and lightly active C4 slag (40mm maximum grain) | 15            | 450                                         | 450                | 450                  | –                                      | –     | –       |
| Sand of medium grain with a dusty clay fraction of 0 % | 30            | 250                                         | 250                | 250                  | –                                      | –     | –       |
| Sand of medium grain with a dusty clay fraction of 0 % | 60            | 120                                         | 120                | 120                  | –                                      | –     | –       |

The total thickness of the pavement is 117 cm.
Calculation of frost resistance.
The design is considered frost-resistant if the condition is met:
The calculation is made using the nomogram. With a pavement thickness of 117 cm, this condition is met. Frost resistance is provided.

Calculation of elastic deflection. Strength criterion has the form:

\[ E_{rev} > E_{min} K_{pr}^{res} \]

where \( E_{rev} \) is the total calculated modulus of elasticity of the structure, determined by the nomogram;

\( E_{min} \) – the minimum required modulus of elasticity of the structure, determined by the empirical formula;

\( K_{pr}^{res} \) – the required coefficient of strength according to the criterion of elastic deflection (for roads of the II category \( K_{pr}^{res} = 1.2 \));

\[ E_{min} = \sqrt{\frac{0.698.65}{\sum N_p - c}} \sum \]

where \( p \) is the calculated pressure on the coating;

\( \sum N_p \) – the number of applications of the estimated lane load for the standard service life;

\( c \) is an empirical parameter equal to the calculated load: A-10 – 3.55; A-11.5 – 3.20.

As a result of the calculation, we obtain:

\[ E_{min} = 325 \text{ MPa} \]

\[ E_{rev} = 394.25 \text{ MPa} \]

The structural strength coefficient obtained by calculation is equal to:

\[ K_{pr} = \frac{E_{rev}}{E_{min}} = \frac{394.25}{325} = 1.21 \]

The required strength factor \( K_{pr}^{res} \) is 1.2.

**Durability is ensured.**

Calculation of the design of non-rigid pavement under the condition of shear stability of underlying soil and loosely coupled structural layers.

Inadmissible shear deformations in the structure will not accumulate if the condition is provided in the soil of the subgrade and in loosely coupled (sandy) layers:

\[ 0 \leq \frac{T}{K_{pr}^{res}} \]

where \( T \) is the active shear stress from the current short-term or long-term load;

\( T_{pr} \) – ultimate shear stress, exceeding which causes a violation of shear strength;

\( K_{pr}^{res} \) – the required coefficient of strength (for roads of the II category \( K_{pr}^{res} = 1.0 \));

The calculation is carried out separately on the ground (heavy loam) and on the sand.

Active shear stresses are determined by the nomogram. The calculated elastic moduli for the layers of the pavement are assigned from the condition of short-term loading.

According to the nomogram and formulas, we determine the calculated coefficient of strength \( K_{pr} \).

As a result of calculating the shear in the soil, we obtain \( K_{pr} = 1.41 \)

Required strength factor \( K_{pr}^{res} = 1.0 \)

Durability is ensured.

When calculating the shear in the sand, we obtain \( K_{pr} = 1.1 \)

Required strength factor \( K_{pr}^{res} = 1.0 \)

**Durability is ensured.**

Design calculation for the resistance of monolithic layers to fatigue fracture from tensile bending.

The calculation is based on the condition:

\[ \sigma_r \leq \frac{R_N}{K_{pr}^{res}} \]

where \( K_{pr}^{res} \) – the required coefficient of strength taking into account the given reliability (for roads of the II category \( K_{pr}^{res} = 1.0 \));
$R_N$ is the tensile strength of the layer material in bending taking into account fatigue phenomena; $\sigma_r$ is the largest tensile stress in the monolithic layer.

$\sigma_r$ is determined using the nomogram, leading the real construction to a two-layer model. All asphalt concrete layers are referred to the upper layer of the model.

As a result of the calculation, we obtain:

$R_N = 2.26$ MPa;
$\sigma_r = 1.0676$ MPa

The structural strength coefficient obtained by calculation is equal to:

$$K_{pr} = \frac{R_N}{\sigma_r} = \frac{2.26}{1.0676} = 2.12$$

The required strength factor is 1.

**Durability is ensured.**

Thus, the presented pavement meets all calculation conditions when exposed to a short-term (dynamic) repeating load.

Now we check the same pavement for the perception of a long load. The initial parameters for the calculation are the same, but for a static state.

**Design characteristics of pavement layers.**

The calculated characteristics for soil, sand, crushed stone and slag-crushed stone bases remain the same as for dynamic calculation. The calculated characteristics of monolithic layers of pavement for static calculation are shown in Table 4.

| Layer material                                          | Thickness, cm | Shear modulus, MPa |
|---------------------------------------------------------|---------------|--------------------|
| Dense asphalt concrete type B with added bitumen 90/130 | 5             | 300                |
| Porous asphalt concrete with sand with added bitumen 90/130 | 7             | 280                |

The total thickness of the pavement is 117 cm.

Calculation of the long-term load on shear stability in weakly connected layers.

The calculation of shear stability under static load is carried out as well as for dynamic, but taking into account static parameters.

Accounting for shear resistance is carried out under the condition:

$$T \leq \frac{T_{pr}}{K_{pr}}$$

where $T$ is the active shear stress from the current short-term or long-term load;

$T_{pr}$ – ultimate shear stress, exceeding which causes a violation of shear strength;

$K_{pr}$ – the required coefficient of strength (for roads of the II category $K_{pr} = 1.0$);

The calculation is carried out separately on the ground (heavy loam) and on the sand

Active shear stresses are determined by the nomogram. The calculated elastic moduli for the layers of the pavement are assigned from the condition of short-term loading.

According to the nomogram and formulas, we determine the calculated coefficient of strength $K_{pr}$

As a result of calculating the shear in the soil, we obtain $K_{pr} = 2.97$

Required strength factor $K_{pr}^{res} = 1.0$

Durability provided.

When calculating the shear in the sand, we obtain $K_{pr} = 0.82$

Required strength factor $K_{pr}^{res} = 1.0$

**Durability is not ensured.**

Thus, the calculation clearly shows that the pavement fully meets the regulatory conditions when exposed to short-term (dynamic) loads, when exposed to a static load, it is not able to provide the required strength. This design of pavement requires adjustment, after which it must again be calculated before ensuring strength according to all criteria [5].
4. The need to calculate pavement for static load

The current regulatory documents (ODN 218.046-01, PNST 265-2018) indicate the requirements according to which it is necessary to check the design of pavement for long-term (static) load. It also lists the cases in which such a check is necessary. However, one should not forget that the probability of stopping vehicles for a long period of time (more than 10 minutes) exists not only in the cases specified in ODN 218.046-01 and PNST 265-2018.

This primarily concerns city streets and roads where there are intersections with traffic lights, the carriageway is often used for stops and parking, and the phenomenon of traffic jams is also widespread [9]. That is, in the city there are practically no places where the car for one reason or another could not be stopped for 10 minutes or more.

Therefore, in urban conditions, the calculation of the static load is required.

Also, carriageways of suburban highways should not be discounted, which are not as much as in cities, but also have a static effect on the carriageway [14]. We consider several such cases:

1. Traffic accidents.
   In this case, whole traffic flows stop and the static effect on the coating is quite significant [7].
2. Traffic jams.
   It is no secret that traffic jams are not a rare occurrence on suburban highways, especially during the summer season, and in “narrow” sections cars stand idle for much more than 10 minutes.
3. Low speed in the territories of industrial enterprises, shopping centers, parking lots, etc.

Calculation of short-term load is made from the condition that the time the impact of the wheel on the road is 0.1 sec. However, at low speed this condition is not satisfied. Therefore, a check for static impact in this case is necessary [11].

5. Findings

Currently, there are several methods for calculating non-rigid structures of pavement. The main, most popular of them are:

- Calculation methodology according to ODN 218.046-01 “Designing non-rigid road pavement”, approved and enforced by the Order of the State Road Service “Rosavtodor” of the Ministry of Transport of the Russian Federation dated December 20, 2000 No. OC-35-P.
- Calculation procedure according to PNST 265-2018 “General automobile roads. Designing non-rigid pavements”, approved by the order of Rosstandart of 04/11/2018 No. 3-PNST.

In addition to these documents for the design and calculation of pavement, the data of other applicable regulatory documents are used: GOST R 52748-2007 “Regulatory loads, design load schemes and approximation dimensions”; GOST 32960-2014 “General automobile roads. Regulatory loads, design load schemes”, SP 34.13330.2012 “Roads”, etc. All of them have the status of “active” and are actively used in the Russian Federation for the design of roads. Therefore, before starting the design and calculation of pavement, it is necessary to decide what regulatory documents to use in specific conditions.

An example of calculating pavement on the dynamic and static effect of a car’s wheel on a coating showed that pavement that fully meets regulatory conditions when exposed to a short-term (dynamic) load is not able to provide the required strength when exposed to a static load.

An analysis of the current conditions of road transport in urban conditions and on country roads convincingly proves that the probability of stopping transport on any part of the road is very high, and therefore the statistical effect on the coating of a car’s wheel cannot be discounted.

Thus, in order to increase the service life of road pavement, the calculation for long loads must be performed under any traffic conditions of vehicles, not limited to the recommendations of regulatory documents.

References

[1] Apestin V K, Shak A M and Yakovlev Yu M 1977 Testing and evaluation of the strength of non-rigid road clothes (Moscow: Transport) 102 p
[2] Babkov V F A review of experimental work on measuring stress in the ground *Studies of methods for calculating the thickness of road surfaces: Proceedings of DorNII. Edition of Gushosdor* vol I pp 156–231

[3] Vasiliev A P 2004 Reference encyclopedia of the road builder *Repair and maintenance of roads in 2 volumes*. Moscow

[4] Vasiliev A P 2010 *Operation of highways*: in 2 volumes, vol 1 (Moscow: Publ. Center "Academy") 320 p

[5] Ivanov N N 1973 *Design and calculation of non-rigid pavement* (Moscow: Transport) 328 p

[6] Korochkin A V 2012 The study of hard road pavement with asphalt concrete pavement in urban conditions *Transport construction* 7 8–11

[7] Korochkin A V 2011 Calculation of rigid pavement taking into account the impact of a moving vehicle *Science and technology in the road industry* 2 8–10

[8] Korochkin A V 2011 Studying the impact of a moving vehicle on the construction of pavement *Building Materials* 1 28–9

[9] Korochkin A V 2015 On the dynamic effect of a vehicle on the construction of road clothes *Roads and Bridges* 33/1 30–3

[10] Krasikov O A 2006 *Strength assessment and calculation of reinforcement of non-rigid pavement* (Almaty: KazgosINTI) 308 p

[11] Nemchinov M V 1985 *Coupling qualities of road surfaces and traffic safety of cars* (Moscow: Transport) 231 p

[12] Silyanov V V and Domke E R 2008 Transport and operational qualities of highways and city streets: a textbook for students. higher textbook. institutions (Moscow: Publishing Center "Academy") 352 p

[13] Savchenko E T and Maksin M O 2016 Analysis of the feasibility of the construction of asphalt concrete and cement concrete road pavements *Young Scientis* 21 204–7

[14] Radovsky B S and Ilyev E B 1976 Modern trends in the design of pavement on roads with heavy traffic *Construction and operation of roads* 4 (Moscow: TSBNTI Minavtodor of the RSFSR) 39 p

[15] Rukavishnikova E E, Lubkina K A and Skvortsov A V 2015 *Road Design at IndorPavement* (Tomsk: Tomsk University Press)