Impact of traffic speed on the strength of highway pavements

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Abstract. The paper touches upon the issues related to the influence of the speed of traffic flow on the calculation of the strength of road pavements of highways. The dependence of the calculated parameters on the vehicle speed is shown. The definitions of such concepts as the design speed of movement on the road, the permitted speed of movement and the actual speed are given. The authors give the values of normative design indicators related to the speed of movement, which were determined more than 50 years ago for the speed of movement of trucks 40-60 km / h, and have remained unchanged since then. The paper also presents the results of the research on the speed of traffic flows along two highways M-2 “Crimea” and M-9 “Baltia” for 16 years, which prove that the speed limit on modern highways has changed dramatically in recent years and does not meet the requirements and design parameters. According to own research and research of many modern scientists, the author proposes to take into account the speed of 110 km / h when determining the design parameters for the calculation of road pavements and to use the dynamic coefficient equal to 1.85 (instead of 1.3) when calculating the pavement instead of standard values and take into account the time of the impact of the wheel on the coating of 0.014 s (instead of 0.1 s).

1. Problem statement

The study of the speed of movement of traffic flows on highways showed that the actual speed of movement has increased significantly in recent years. Due to this fact some of standard parameters associated with the speed limit and used in the design of road pavements no longer meet modern conditions, since they were calculated for vehicles moving at much lower speeds.

First of all, two calculated parameters require correction: the dynamic coefficient and the time of impact on the wheel of a moving vehicle on the road surface. The existing standard values of these design parameters were determined 50-30 years ago for speeds of 40-60 km / h.

Nowadays, the values of these parameters recommended by legal documents are as follows:
- Dynamic factor $F_d = 1.3$;
- Application time of the dynamic load of a vehicle car wheel to the coating $t = 0.1$ s

The research and analysis of scientific developments of a number of modern scientists allow recommending the following values of the design parameters for the design of pavements of highways:
- Dynamic factor $F_d = 1.8$;
- Application time of the dynamic load of a vehicle car wheel to the coating $t = 0.014$ s.
2. Introduction
According to modern methods, the design of road pavements of both rigid and non-rigid types is carried out for static and dynamic loads. The static load is taken into account during the design of the pavement of parking lots, bus stops, cargo terminals, etc. At the same time, the pavements of the roadways of highways and city streets are design for dynamic load. Taking into account the fact that the dynamic load exceeds the static one, especially at high speeds and high traffic intensity, the strength of the pavement and its design depend on it [1].

The main design parameters for the determination of the dynamic load are the dynamic factor and the time of application of the load from the vehicle wheel to the road surface. Both of these parameters depend on the speed of traffic. That is, the speed of movement, along with the intensity of traffic, is one of the most important characteristics on which the design and construction of pavement depends [2].

It is necessary to note that for the design and operation of highways, several concepts of traffic speeds are determined. First of all, it is necessary to note that there are standard traffic speeds, that is, those that are recommended by legal documents and the actual traffic speed. Standard traffic speeds include:

- Design speed of a vehicle. The design speed depends on the road category. Depending on the design speed, geometric parameters of highways are assigned (radii of curves in the plan and longitudinal profiles, maximum longitudinal slopes, width of the traffic lane of the roadway and exits of interchanges, etc.);

- Permitted speed of a vehicle. The permitted speed is related to traffic safety and is determined by the rules of the road.

Actual traffic speed is the actual speed at which traffic is moving along the road. It is not a constant value, but depends on many factors such as: the technical condition of the road, traffic intensity, especially road conditions, means of traffic flow regulation, natural and climatic conditions, etc. In addition, the speed of movement in the traffic itself is not the same. Someone moves faster, someone slower. Therefore, such a concept as a percentage speed provision was introduced. For example, a 15% speed provision indicates the speed of slow moving cars. The 50% provision corresponds to the average speed of traffic flow of 85% provision - a speed that does not exceed the bulk of cars [3]. Thus, according to the speed of 85% provision, certain decisions are made to regulate traffic flows.

3. Methods
The study of the speed of the traffic flow, as well as the traffic intensity on the studied highways was carried out using 24-hour video recording. On the basis of which the hours of “peak” loads were determined. The studies covered all seasons: summer, autumn, winter, spring. For greater objectivity and reliability, the observations and video recording were carried out throughout the whole week, which allowed obtaining the data on traffic speeds both on weekdays and on weekends and holidays.

Thus, the video was filmed four times a year (each season), seven days a week and 24 hours a day. The determination of the speed of traffic flows was carried out in office based on the results of video recordings. This makes it possible to confidently speak about the maximum reliability and accuracy of the research results.

4. Results
4.1. Design speed of a vehicle
As it was mentioned above, during the design of motor roads, their geometric characteristics are assigned taking into account the design speed. These include: radii of curving angles, values of longitudinal slopes, width of the roadway and shoulders, etc. Design traffic speed is the maximum possible speed at which a vehicle can theoretically move on a given road. Therefore, as a rule, real road speeds are limited to values lower than the design speed.

The design speed is assigned in accordance with SP 34.13330.2012 “Highways” [4]. For roads of category IA, the design speed is 150 km / h. For motor roads of categories IB and II it is 120 km / h.
For roads of category IB and III it is 100 km / h, for IV category it is 80 km / h, V category it is 60 km / h. The design speed for streets and city roads is assigned in accordance with SP 42.1333.2011 “Urban planning” and with unregulated traffic it is 100 km / h and with regulated traffic it is 80 km / h.

4.2. Permissible speed

The permissible speed on highways is assigned in accordance with the “Traffic Regulations of the Russian Federation” (TR). According to traffic rules on highways (the highways of IA and IB categories) the permissible speed is 110 km / h, on other roads it is no more than 90 km / h. The exception is the highways of State Company Avtodor, where the permissible speed is 130 km / h. In cities, according to traffic regulations, the permissible speed does not exceed 80 km / h. Figures 1 and 2 show the road signs indicating the permissible speeds [5].

![Figure 1. Road signs on highways](image1)

![Figure 2. Road signs on highways and city streets. Actual traffic speeds](image2)

In 2003-2019 the author carried out research on a number of highways. One of the tasks of the research was to determine the actual traffic speeds on modern highways [5]. We will consider the results obtained as a result of the research on the example of sections of two roads: M-2 “Crimea” and M-9 “Baltia”.

On the M-2 “Crimea” highway, the studies were carried out along traffic lines in two sections; Section 1 (six lines) km 49 + 000 - km 59 + 000; Section No. 2 (four lines) km 98 + 000 - km 104 + 000. The traffic speed on sections of these highways was of 90% provision (Table 1).
Table 1. Traffic speed on the sections of these highways of 90% provision

| Year | Section №1 km/h |          |          | Section №2 km/h |          |
|------|-----------------|----------|----------|-----------------|----------|
|      | Right line      | Middle line | Left line | Right line      | Left line |
| 2003 | 82,0            | 96,5     | 117,5    | 81,5            | 103,2    |
| 2009 | 85,1            | 97,2     | 117,9    | 82,6            | 105,0    |
| 2015 | 87,4            | 98,3     | 118,3    | 88,4            | 106,1    |
| 2019 | 89,8            | 101,4    | 120,8    | 89,5            | 108,4    |

In addition, the maximum speeds of individual vehicles were recorded. The maximum speed of a passenger car was recorded at section No. 1 and was 184 km / h. The speed of freight car on the same section № 1 was 154 km / h.

On the highway M-9 “Baltia”, a section with four lines of km 85 + 000 - km 95 + 000 was studied. The results of the study of 90% provision are presented in Table 2.

Table 2. Research results of 90% provision

| Year | Km/h       |          |
|------|------------|----------|
|      | Right line | Left line |
| 2003 | 91,8       | 122,4    |
| 2009 | 93,4       | 123,1    |
| 2015 | 96,8       | 125,6    |
| 2019 | 99,1       | 127,5    |

Here the cases when the speed of cars reached 160-170 km / h, and the speed of trucks - 130-140 km / h were determined.

It is necessary to note that on the M-2 “Crimea” and M-9 “Baltia” highways the permissible speed is 110 km / h and the design speed is 120 km / h.

Usually, both in the Russian Federation and in many foreign countries, the 85% level of provision is used to determine the actual speeds. However, taking into account that in Russia the share of violations associated with exceeding the speed of traffic is very high, the author believes that for the design of road pavements, it is necessary to take 90% level of provision.

The research on traffic flow was carried out by the author using photo and video recording, as well as when driving in a traffic flow in different modes. The average speed of the traffic flow during the day was recorded. It is necessary to note that the measurements were carried out at the same sites, in the same years and at the same time as traffic intensity.

According to the results of the study, it is possible to conclude that, in general, the traffic flow is moving exceeding the permissible speed. In this case, the clause of the traffic regulations on the possibility of exceeding the speed by 19 km / h plays an important role. That is why the average speed of cars is higher than the permissible one.

4.3. Design parameters depending on traffic speed

The parameters used for the design of road pavements and related to the speed of traffic flow were mentioned above: dynamic factor and the time of interaction of the wheel with the road. Both of these parameters are normative. The problem lies in the fact that the values of these parameters were determined back in the 60s - 80s of the last century by the founders of the modern methodology N.N. Ivanov. [6], Birulya A.K. [7], Babkov V.F. [8] and others. However, at the same time, these parameters were determined for the conditions corresponding to the time when the carrying capacity of trucks was 3-10 tons and their speed did not exceed 40-60 km / h.

Nowadays on our roads, trucks and road trains with a carrying capacity of 40-60 tons carry out freight transportation, while the speed of movement, as can be seen from the materials presented
above, is 90-120 km / h. That is, the conditions for the movement of traffic flows have undergone significant changes, while the calculated parameters have remained unchanged. Taking into account the above mentioned research results, the author proposes to consider the speed of traffic flow equal to 110 km / h during the design of the pavement and design parameters.

Thus, according to the current PNS 265-2018 “Design of non-rigid road pavements”, put into effect by the Order of the Federal Agency for Technical Regulation and Metrology of 11.04.2018 No. 3-PNS [9], ODN 218.046-01 “Design of non-rigid road pavements” approved by the order of Rosavtodor dated 20.12.2000 No. OS-35-R [10] and “Methodological recommendations for the design of rigid road pavements (instead of VSN 197-91)”, enacted by the order of the Ministry of Transport of the Russian Federation of January, 3, 2003 No. OS-1066 -p [11] road pavements should be designed for short-term repeated action of moving loads equal to 0.1 s. Exactly the same exposure time 0.1 s. VSN 46-83 was also laid, approved by the order of the USSR Ministry of Transport Construction in May 29, 1983 No. LN-550.

Now let us perform a calculation. According to PNS 265-2018, the diameter of the track of the driving wheel of a car at a standard load of 115 kN is 34 cm. The duration of the increase in the load with this diameter at different speeds will be expressed in the values presented in Table 3.

Table 3. Duration of the load increase with a track diameter of a driving wheel of 35 cm at various speeds

| Speed, km/h | 110 | 100 | 60 |
|------------|-----|-----|----|
| Speed, s   | 0.011 | 0.012 | 0.020 |

As it can be seen, the load application time is hundredths of a second. At the speed of 110 km / h it is an order of magnitude less than the standard value equal to 0.1 s. That is, the standard values of the time for the application of load from the wheel to the surface are outdated and no longer meet modern requirements.

The same can be said about the dynamic factor.

5. Discussion

In the existing legal documents for the design of road pavements PNS 265-2018, ODN 218.046-01, Methodological recommendations for the design of rigid road pavements (instead of VSN 197-91), a dynamic factor equal to 1.3 is used in the design of road pavements. The same value of the dynamic factor is also reflected in the previously existing VSN 46-83 "Instructions for the design of non-rigid pavements" and VSN 197-91 “Instructions for the design of rigid pavements”. This coefficient was calculated for speeds of 40-60 km / h.

The problem of the determination of the real dynamic coefficient is devoted to the research of many modern scientists - Smirnov A.V., Radovsky B.S., Suprun A.S, Konorev A.S., Woodrooffe J.H., Cebon D, etc. Thus, according to the formula proposed by B.S. Radovsky [12], the dynamic factor at a speed of 110 km/h is \( F_d = 1.46 \). According to the calculations of Professor A.V. Smirnov [13] at the same speed of movement \( F_d = 1.78 \). Konorev A.S. [14] at 110 km / h, the dynamic coefficient reaches \( F_d = 2.1 \). The author also conducted research in this direction [15]. The graph of the dependence of the dynamic factor on the speed of movement obtained by him is shown in Figure 3.
As it can be seen from the graph, the dynamic factor in this case for a speed of 110 km/h is equal to $F_d = 2.25$. The presented results are approximate, since the inertial and damping properties of the base of the pavement were not taken into account during the construction of the spatial model of the stress-deformed state. However, the obtained solution quite accurately reflects the tendency of road structure deflections to grow with the increase in the speed of traffic flows.

Having analyzed and summarized the results of various studies carried out both by the author and by other Russian and foreign scientists, the author believes that it is advisable to take the dynamic coefficient $F_d = 1.85$ for a speed of 110 km/h.

Thus, we found out that the calculated parameters associated with the speed of traffic flow, currently used with the existing method for the design of road pavements, are determined for road traffic conditions that are fundamentally different from those that we actually have on our roads. Consequently, as a result of their use, we get pavement designs that do not meet modern conditions, which significantly reduce the performance of pavements, their strength and durability.

**6. Conclusion**

The studies of traffic speeds allowed establishing that the average speed of movement of both cars and trucks on highways is growing annually and now it reaches 108.4-127.5 km/h on the extreme left lines, 89.5-112 on the extreme right lines, 0 km/h at a permissible speed of 110 km/h (130 km/h). However, the parameters used for the design of pavements and depending on the traffic speed, such as the dynamic factor and the load time, which are currently proposed by the regulations, were calculated at a speed of 45-60 km/h. Therefore, in order to obtain more reliable results of pavement design, the author proposes to apply the design indicators calculated at a speed of 110 km/h.

In addition, during the design of road pavements the author proposes to take into account the time of application of the wheel load to the surface equal to 0.014 s, which is more consistent with the
existing conditions. For the same reason, it is proposed to take the dynamic factor \( F_d = 1.85 \) instead of the normative \( F_d = 1.3 \).

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