Investigation of the suspension of vehicles moving on stone roads

Umar Vakhidov[1], *Vladimir* Makarov[1,2,*], *Vladislav* Klubnichkin[2], *Evgeny* Klubnichkin[2], and *Vladimir* Belyakov[1]

[1]Nizhny Novgorod State Technical University n.a. R.E. Alekseev, 603950, Minina str., 24, Nizhny Novgorod, Russia
[2]Bauman Moscow State Technical University, 105005, 2th Baumanskaya str., 5/1, Moscow, Russia

Abstract. The paper studies the problem of traffic on mountain roads of natural origin. A mathematical model of a natural stone road is presented, the paper demonstrates also diagrams of "floodplain surface vs. support bed slope" correlation function. The calculation of the ride comfort of vehicles utilizes a four-mass model. Calculation results are demonstrated for a GAZ-3308 truck, as well as for a vehicle with half the suspension rate. The result obtained shows 30-50% reduction of the vibration load at a suspension rate reduction by 50%, dependent on the road type. The travel speed can be increased by 45% dependent on the road type and driver's work time.

1 Introduction

More than a half of the territory of the Russian Federation is occupied by mountains and highlands. The mountainous regions of Russia concentrate vast and various natural resources. Mountainous territories are living and economic activity areas of numerous nationalities. In order to foster the development of such regions, it is vitally important to assure transport interconnection of all territories of the country. It is specific for many remote mountainous districts that the most scope of cargo transport and handling is performed along floodplains of rivers having specific geometric, physical and mechanical properties. See an example of truck driving on a floodplain of a mountain river in Fig. 1.

The studies by the authors demonstrate that stone roads can be classified as follows [2]:
- by origin (natural and artificial);
- by support bed property (beaten and virgin);
- by boulder size (roads with small stones, roads with stones comparable with the locomotor size, roads with stones comparable with the vehicle size);
- by stone shape (irregular or round shape);
- by presence of water;
- by support bed slope.

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* Corresponding author: makvl2010@gmail.com

Fig. 1. GAZ-3308 "Sadko" truck driving on a floodplain of a mountain river [1]

It is the support bed slope that influences the stone sizes and the roughness of the road. The greater the support bed slope angle to the horizon, the bigger is the fraction of rocky inclusions. Within the scope of the present paper, the influence of the roughness of stone roads on the ride comfort of automotive vehicles is analyzed.

2 Mathematical model

2.1 Assumptions

For the calculation of the ride comfort of wheel type vehicles on stone roads we assume the following:
- the geometrical parameters of the support surface are stipulated by round shape stone sizes;
- the sag of the support surface is totally negligible;
- the fraction of the rocky inclusions is determined by the slope angle of the ride surface plane to the horizontal plane, the lower is the slope, the smaller is the size of the boulders;
- a section of the surface of a specific road section is the implementation of the profile, whereas a multitude of such implementations represents the road profile as a random process;
- for ride comfort calculation, a four-mass model is used.

2.2 Mathematical model of stone roads

As studies [3-5] demonstrate, the probability characteristics of the support surface roughness could be described by R_q (l) correlation function reflecting the probability relationship between the micro-profile coordinates along l way section. Previously, the authors of [6, 7] have obtained correlation function values for stone roads with different inclination angles. An example is shown in Fig. 2.
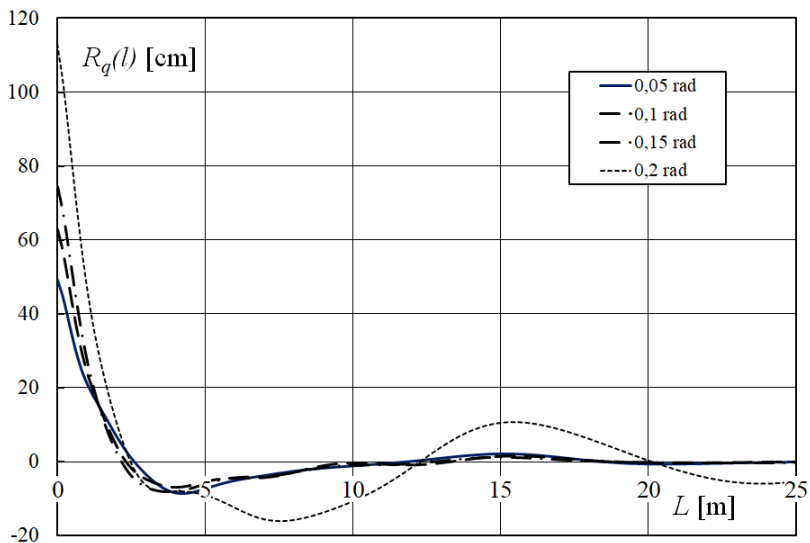
Fig. 2. Correlation function diagram "Floodplain surface roughness vs. support bed inclination angle"

2.3 Mathematical model of vehicle

For the ride comfort calculation of vehicles, the calculation diagram for suspension specifications [8, 9] is utilized, see Fig. 3.
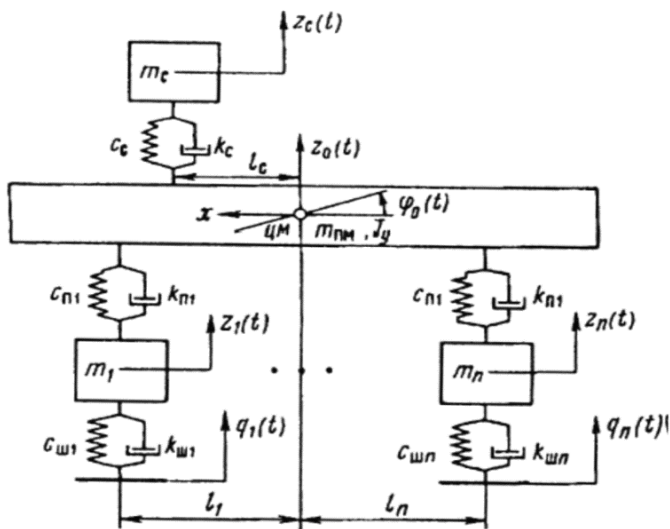

Fig. 3. Calculation diagram for suspension specifications

For ride comfort calculation, the following dependencies were utilized:

$$m_i \ddot{z}_i + (k_{si} + k_{wi})\dot{z}_i + (c_{si} + c_{wi})z_i - k_{si}(\dot{z}_0 + l_i\dot{\varphi}_0) - c_{si}(z_0 + l_i\varphi_0) = k_{wi}\dot{q}_i + c_{wi}q_i;$$

$$m_{sm}\ddot{z}_0 + \dot{z}_0 \sum_{i=1}^{n} k_{si} + z_0 \sum_{i=1}^{n} c_{si} + \dot{\varphi}_0 \sum_{i=1}^{n} k_{si}l_i + \varphi_0 \sum_{i=1}^{n} c_{si}l_i + k_c(\dot{z}_0 + l_c\dot{\varphi}_0) +$$

$$+ c_c(z_0 + l_c\varphi_0) = k_c\dot{z}_c + c_c z_c + \sum_{i=1}^{n} (k_{si}\dot{z}_i + c_{si}z_i);$$

$$J_y\ddot{\varphi}_0 + \dot{\varphi}_0 \sum_{i=1}^{n} k_{si}l_i^2 + \varphi_0 \sum_{i=1}^{n} c_{si}l_i^2 + \dot{z}_0 \sum_{i=1}^{n} k_{si}l_i + z_0 \sum_{i=1}^{n} c_{si}l_i + k_c(\dot{z}_0 + l_c\dot{\varphi}_0)l_c +$$

$$+ c_c(z_0 + l_c\varphi_0)l_c = (k_c\dot{z}_c + c_c z_c)l_c + \sum_{i=1}^{n} (k_{si}\dot{z}_i + c_{si}z_i)l_i;$$

$$m_c\ddot{z}_c + k_c\dot{z}_c + c_c z_c = k_c(\dot{z}_0 + l_c\dot{\varphi}_0) + c_c(z_0 + l_c\varphi_0).$$

(1)

In formulas (1), $z_0(t)$, $z_i(t)$, $z_c(t)$ are generalized coordinates characterizing the vertical travels of the center of mass of the spring borne vehicle part, the mass of the non-cushioned part of the ith axle, $\phi_0(t)$ are generalized coordinates characterizing angular displacement of the spring-borne mass relative to its center of mass; $q_n(t)$ is the kinematic disturbance to the ith axle wheels; m_{sm}, m_c, m_i are the masses of the spring borne vehicle part, of the seat with a person, of the spring borne part of the ith axle and the driving axle, respectively; J_y is the moment of mass inertia of the spring borne part relative to the transversal axis y passing through its center of mass; k_{si}, k_{wi}, k_c are reduced to the center contact spots of the tire with the support surface (track) damping rates of the suspensions and the tires of the ith axle, of the seat, c_{si}, c_{wi}, c_c are reduced to the center contact spots of the tire with the support surface (track) suspension rate and stiffness rates of the tires of the ith axle, and of the seat; l_i is the distance from the center of mass of the spring borne part to the ith axle, l_c is the distance from the center of mass of the spring borne part to the seat; i is the axle number; n is the number of the axles.

3 Calculation results

In order to define the disturbing impact $q_n(t)$ in formulas (1), the road roughness with the characteristics specified in Fig. 2 was modeled as a harmonics sum. An example is shown in Fig. 4.
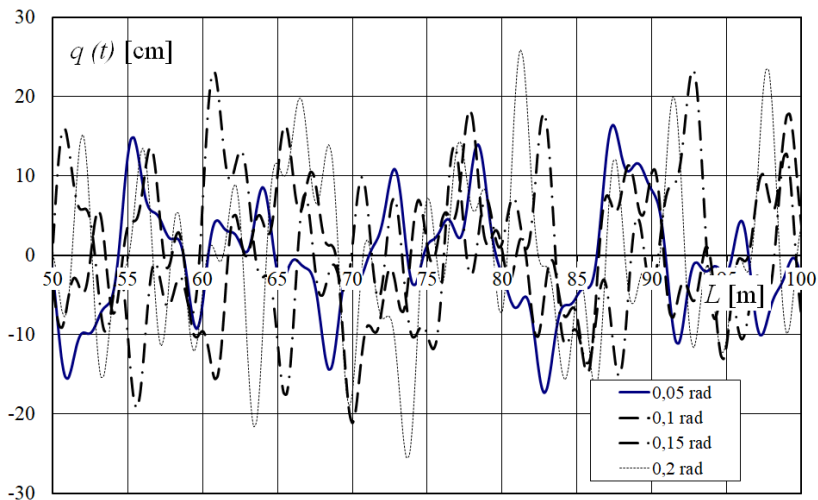
Fig. 4. Stone road roughness example

Based on the roughness data, the calculation diagram in Fig. 3 and formulas (1), we calculate the reduced vibration acceleration values on the driver's seat. In accordance with GOST 12.1. 012 "Vibration safety. General requirements", we determine the admissible driver's work time.

Fig. 5 shows data for a truck with specifications similar to those of GAZ-3308, as well as of a vehicle with half the suspension rate.
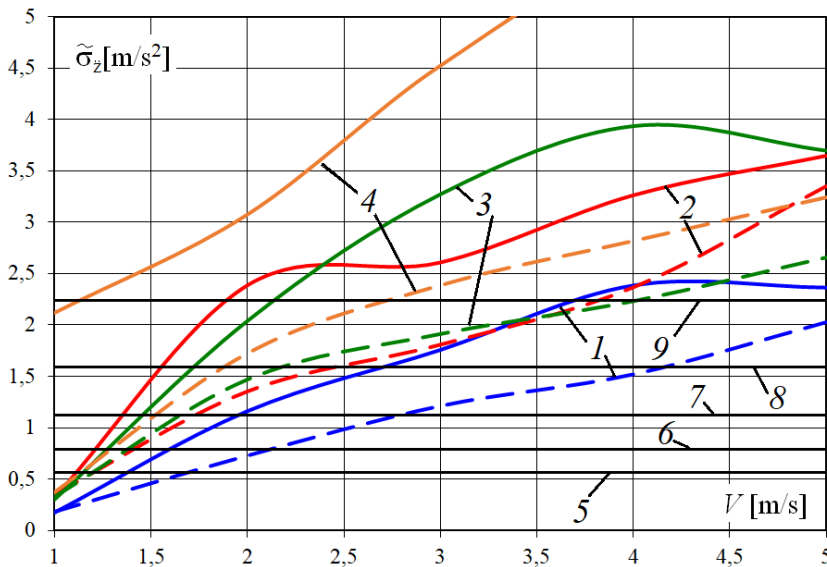

Fig. 5. Diagrams of reduced rms accelerations in driver's seat dependent on the travel speed of GAZ-3308 truck on stone roads

Fig. 5 shows dependencies of reduced rms accelerations dependent on the travel speed of a GAZ-3308 truck on stone roads with different slope angles to the horizon. Solid lines represent the standard suspension of the truck, the dashed lines represent represents a suspension with half the suspension rate. The numbers show rms accelerations for roads with

different slope rates: *1* – 0.05 rad, *2* – 0.10 rad, *3* – 0.15 rad, *4* – 0.20 rad. The horizontal lines indicate the rated work time values: *5* – 8 hrs, *6* – 4 hrs, *7* – 2 hrs, *8* – 1 hr, *9* – 0.5 hr.

4 Conclusions

The paper presents mathematical models describing the roughness of stone roads and the ride comfort of vehicles. Based on such models, calculations were made for assessment of the influence of the suspension rate on driver's work time. The obtained admissible speed values for GAZ-3308 trucks on stone roads are: 1.4-3.7 m/s with standard suspension and 1.7-5.4 m/s with a suspension with half the suspension rate on 0.05 rad slope; 1.1-1.9 m/s with standard suspension and 1.2-3.8 m/s with a suspension with half the suspension rate on 0.10 rad slope; 1.15-2.12 m/s with standard suspension and 1.2-4.05 m/s with a suspension with half the suspension rate on 0.15 rad slope; less than 1.15 m/s with standard suspension and 1.15-2.75 m/s with a suspension with half the suspension rate on 0.20 rad slope (the less value applies to 8 hrs driver's work time, the greater value applies to 0.5 hrs driver's work time). The analysis the obtained data demonstrates 30-50% reduction of the vibration load at a suspension rate reduction by 50%, dependent on the road type. The travel speed can be increased by 45% dependent on the road type and driver's work time.

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