USEFUL RELATIONSHIPS BETWEEN VEHICLE VIBRATION AND SIDE ROCK SLOPE STABILITY

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ABSTRACT
The stability of rock slopes on roads is an increasingly relevant issue that is very often neglected during construction. The results of a real-life experiment on the influence of vehicle vibrations on roadside rock slopes are shown. The acceleration, frequency and displacement of the rock surface during the passage of different vehicles were investigated. Dependencies between the vibration parameters of different types of vehicles, the forms of rock slope oscillation and its stability have been established. The heaviest cars have an adverse effect on rock slopes, just like train cars. The different natural frequency of the highly cracked parts of the rock along the slope predetermines the collapse of those of them that enter into resonance with the induced oscillations. The stronger the rock, the smaller the debris and the higher its natural frequency.

ПОЛЕЗНИ ЗАВИСИМОСТИ МЕЖДУ ТРЕПТЕНИЯТА НА ПРЕВОЗНИТЕ СРЕДСТВА И УСТОЙЧИВОСТТА НА КРАЙПЪТНИТЕ СКАЛНИ ОТКОСИ

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РЕЗЮМЕ
Устойчивостта на скалните откоси по пътищата е все по-актуален проблем, който много често бива пренебрегван по време на строителството. Представени са резултатите от проведен натурен експеримент за влиянието на трептенията от превозните средства върху скалните откоси край пътя. Изследвани са ускорението, честотата и преместването на скалната повърхност по време на преминаване на различни превозни средства. Установени са зависимости между параметрите на трептенията от различните типове превозни средства, формите на трептене на скалния откос и неговата устойчивост. Най-тежките автомобили въздействат неблагоприятно на скалните откоси, точно като жп вагоните. Различната собствена честота на силно напуканите части от скалата по откоса предопределя срутването на онези от тях, които влизат в резонанс с предизвиканите трептения. Колкото по-здрава е скалата, толкова по-дребни са отломките и собствената им честота е по-висока.
Ключови думи: *скален откос, принудени трептения, превозни средства, срутване, резонанс, напукан блок, път.*

<u>Introduction</u>

The stability of rock slopes on roads is a problem that, paradoxically, is becoming more and more relevant in our country. Falling rock blocks and collapsing rock escarpments on roads are becoming more common, especially in late winter. Usually, road administrations explain this fact with climate changes, which in our country are expressed in a greater number of torrential rains, but in the late spring and summer. The statistics show that the month of February has become the driest month of the year. Therefore, the reason for the increased number of road crashes is something else. The report provides an answer to this question with the results of a field study carried out in the summer of 2023 in Bulgaria.

I. State of the Art

From the reviewed about 15 publications, mainly American {1, 2 and 4] and Chinese [6], reflecting the results of such studies, it is clear that the interest of researchers is mainly focused on risk assessment and classification of rock massifs. In this regard, Pierson (1990) [8], who developed the rockfall hazard assessment system in the state of Oregon, and later Budetta P. (2004) [3] modified the hazard assessment system of falling rock blocks, developed by Pierson [8]. Similar systems have been developed by other organizations [5 and 7].

The information on the applied strengthening activities is mainly with nets and ropes or with re-sloping. Regarding the dynamic effect, the spectrum and propagation of soil waves caused by passing trains and the propagation of vibrations from rollers on the construction site were investigated.

There are some important established dependencies in the reviewed literature that relate to the problem under consideration here, and the most important of these is the following:

• The adverse impact of vibrations on adjacent buildings is caused by surface waves (Relay's waves). Their spreading depth does not exceed 60cm when they are caused by the relatively high frequencies of the machines.

In our previous field research from 2019, we proved the technical possibilities for extinguishing the harmful vibrations on the foundations of buildings, and in our theoretical research from 2022, we proposed the hypothesis of the resonance between the vibrations of heavy vehicles and the self-oscillations of rock blocks with the same natural frequency as a generator of the collapses.

II. Aims and objectives of the conducted experiment

The aim is to experimentally confirm the hypothesis that the resonance between the forced vibrations from the heavy vehicles and the natural frequency of the dominant blocks in a highly cracked rock slope induces collapse under certain conditions.

The following tasks were performed for the experiment:

• The exact suitable place for the field research was selected on the Mezdra - Svoge road near Eliseyna station;

• An inspection of the site was made, the crack systems in the massif of the rock escarpment were measured and a standard classification of the massif and the constituent rocks was made;

• With the help of the special equipment, a series of measurements of the accelerations, speeds and displacements of the massif as a result of the vibrations caused by the vehicles on the road and the railway line was carried out.

• All experimental results are systematized and analyzed to find the correlations between them in different logical profiles regarding the impact of resonance on slope resistance, energy-dissipating capacity of the array, compliance with theoretical hypotheses, etc.

III. Geological Site Conditions

The rocks are Diorite Porphyrites - reddish, highly fractured igneous rocks with steep slopes, which in the region of the Iskar gorge have been affected by collapses, as shown in Fig. 1.

The classification of the rock and the rock mass was made according to the standard of the International Society of Rock Mechanics (ISRM) and it falls into the following categories, respectively:

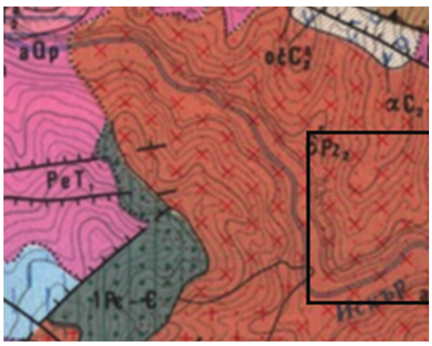

Fig. 1: Geological map of the experiment area

- R4 – Robust Rocks.
- VI - The rock falls into the hard rock category.
- III - The rock falls into the Moderately weathered category.

The array classification is as follows:

- according to the distance between the cracks: 8 bales for a distance from 6cm to 20cm.
- according to the state of the cracks: 0 points for cracks open >5mm and filling in them with a diameter d>5mm.
- according to the hydrogeological conditions: 4 points for water draining from the massif.
- according to crack orientation: (-75) for very unfavorable crack system orientation.Направената количествена оценка на риска показва, че скалният откос е много опасен и лесно може да се срути.

IV. Measurement of oscillations in the vehicle array

Using special electro-acoustic equipment, the accelerations, speeds and displacements of the array were measured as a result of the vibrations caused by the vehicles on the road.

Figure.2: Location of the profile with the road and railway

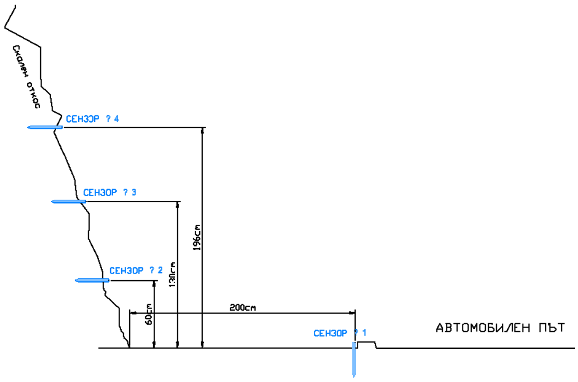

Figure 3: Schematic of the sensor layout

Tables 1, 2 and 3 present the summarized measurement results in points 1, 2 and 4.

Table 1: Grouped results of the measurement in point #1..

№	1	2	3	4	5	6	Extrapolation	
Vehicle	**Car Subaru**	**Van with trailer**	**Jeep**	**Minibus Iveco**	**Mercedes light truck**	**Train**	**TIR 40t**	**TIR 50t**
ω_{r1}, Hz	75	75	75	75	75	75	75	75
$a_{max\,1}$, m/s²	0.2	0.18	0.5	0.5	0.9	13	10.1	12.7
δ_1, μm	1	0.95	2.5	2.5	8	100	99.5	125
ω_{r2}, Hz	98	92, 98	92, 98	92,98	92	95		
$a_{max\,2}$, m/s2	0.18	0.115	0.19	0.19	0.16	8.5		
δ_2, μm	0.85	0.55	0.85	0.85	0.85	40		
Grouping	I group		II group		III group	IV group		

Table 2: Grouped results of the measurement in point #2..

№	1	2	3	4	5	6	Extrapolation	
Vehicle	**Car Subaru**	**Van with trailer**	**Jeep**	**Minibus Iveco**	**Mercedes light truck**	**Train**	**TIR 40t**	**TIR 50t**
ω_{r1}, Hz	75	75	75	75	75	75	75	75
$a_{max\,1}$, m/s²	0.01	0.0075	0.01	0.008	0.008	0.15	0.15	0.15
δ_1, μm	0.08	0.075	0.08	0.04	0.07	0.9	0.9	0.9
Grouping	I group		II group		III group	IV group		

Table 3: Grouped results of the measurement in point #32..

№	1	2	3	4	5	6	Extrapolation	
Vehicle	Car Subaru	Van with trailer	Jeep	Minibus Iveco	Mercedes light truck	Train	TIR 40t	TIR 50t
ω_{r1}, Hz	75	75	75	75	75	75	75	75
$a_{max\ 1}$, m/s^2	0.012	0.021	0.02	0.02	0.013	0.35	0.35	0.35
δ_1, μm	0.09	0.085	0.1	0.1	0.085	3	3	3
Grouping	I group		II group		III group	IV group		

V. Discussion

The resonant frequency of 75Hz here is two to four times higher than that in clay soil. Undoubtedly, a major factor for this is the natural rock environment in the current measurement: the road and railway are directly built on rock, the sensors at the four measurement points also rest on the rock. It is quite logical to obtain a higher eigenfrequency of the rock, much higher than that of the dispersed clay.

The reported acceleration and displacement results are grouped according to their similarity. Thus, in the first group are the results of the Subaru passenger car and the minivan with the trailer. Their results are close, and those of the Subaru passenger car are taken as representative. In the second group, the results of the Jeep and the Iveco minibus are valid, and the Jeep is accepted as representative. The third group is represented by the Mercedes light truck. Train reports are separated in a fourth group. Extrapolating the results from the first three vehicle groups to 40t and 50t cars reaches the same results as the train (Fig. 4).

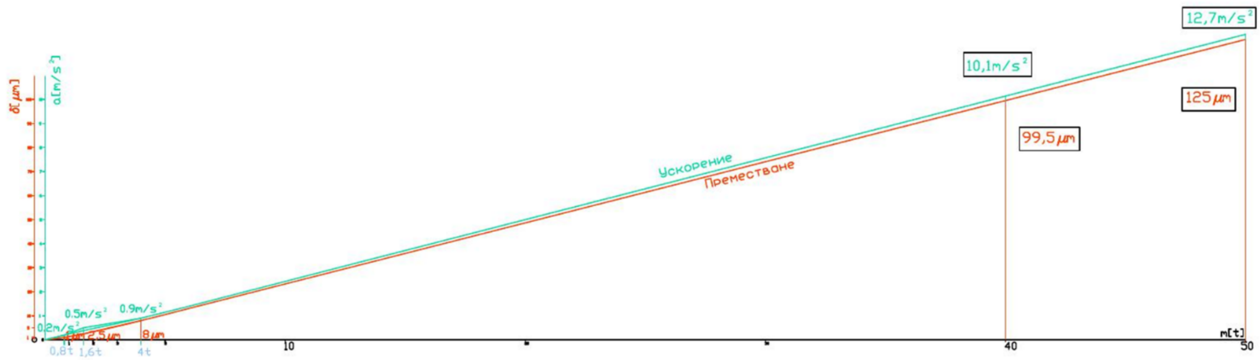

Figure 4: Extrapolation of the results to 40t and 50t vehicles

For point #1, it is evident that the extrapolated results $a=(10.1 \div 12.7) m/s^2$ and $\delta=(99.5 \div 125)$μm for TIR with a mass of 40t or 50t are approximately the same as those of the train $a=13 m/s^2$ and δ=100μm. The mass of a passenger car is about 50t, which is why these results are so similar. Therefore, by the results of the train we can indirectly judge the results of the passing heavy TIR trucks.

Figure 5: Location of point 1

At point #2 for the resonant frequency of 75Hz, the large damping of oscillations from the medium for the distance of 3m separating point #1 from the rock escarpment is visible. The impact of passenger cars and light trucks decreased between 20 and 50 times to insignificant values, and that of the train decreased by about 100 times.

Figure 6: Profile of points 2, 3 and 4.

From the table of extreme values in point #4 for the resonant frequency of 75Hz, the gain of the signal from the increase in the slope height can be seen. Thus, at point #4, the signal amplification compared to base point #2 varies from 15% for light cars to 50% for heavier ones, and for the train, respectively for TIR, the amplification is from 2.5 to 3 times. With a more precise analysis of the signal gain along the slope height, the values can be extrapolated to the crest and according to the oscillation shapes it is possible to obtain much larger and dangerous accelerations and displacements. This issue, however, is also subject to further instrumental measurements in the future.
After all, in point #4, the impact of cars and light trucks is insignificant, and that of the train and TIR has decreased nearly 30 times compared to point #1.
In the low-frequency range from 0 to ~32Hz, the values of accelerations and displacements in all measured points are very close, they go together. Above 32Hz the values gradually separate and the oscillations of point #1 next to the road banquette increase the most. The maximum resonance acceleration of 13m/s2 occurs at a frequency of 75Hz, and the second largest acceleration 8.5m/s^2 is at a frequency of 95Hz.

Between 30Hz and 80HZ, gradually the values of accelerations and displacements at the third and fourth points, which are on the rock slope at a height of 1.33m and 2m from the ground, also begin to increase and exceed those at the second point, which is at the fifth of the slope (at 60cm above the field). In this range, the values at the highest point #4 slightly exceed those at point #3 below it. Therefore, the higher up the slope the point is, the greater the acceleration and displacement.
From 80Hz onwards, however, the values of point #3 start to slightly exceed those of point #4. In this third frequency section, the values at points #3 and 4 increase sharply, approaching those at point #1, while the values at base point #2 remain roughly constant. This change in the spectral pattern could be explained by the adoption of a second form of oscillation of the rock array after passing through the first resonant frequency of 75Hz.
The increase in values and their differentiation along the slope height at higher frequencies, especially after the first resonance, can be explained by local resonances along the uneven rock surface, the cracks and the formed blocks or wedges upwards, the sizes of which are relatively smaller and with more -high natural frequency.

VI. Conclusions

1. The higher eigenfrequency of sound rock suggests collapse of smaller rock debris relative to areas where roads or railways are based on thicker soft Quaternary overburden.
2. The heaviest vehicles (TIR) adversely affect rock slopes, just like railway cars.

3. The subsoil has a strong damping ability, but the large gradient of the steep rock slopes again amplifies the accelerations and displacements coming from the vehicles.

4. The lowest value of the accelerations and displacements caused by the vehicles on the road is at the heel of the rock slope.

5. The different natural frequency of the highly cracked parts of the rock along the slope predetermines the collapse of those of them that enter into resonance with the induced oscillations. The stronger the rock, the smaller the debris and the higher its natural frequency.

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