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BLAST VIBRATION INTENSITY IN THE CHANGING HYDROGEOLOGICAL CONDITIONS

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The attenuation of blast vibration intensity in jointed sedimentary rocks depends not only on geological anisotropy of these rocks but also on hydrogeological conditions there. In mine blasting areas groundwater level in vibration medium varies largely. The vibration measurements were performed in different hydrogeological and geological conditions. Both factors were analysed together and separately, the impact of gravity water content on the vibration attenuation intensity was established and an equation to express this function was worked out.

The water content of rocks varies depending on the season and on the location of blasting site as regards the general water depression of mine. It is necessary to consider it while designing cautious blasting.

Hydrogeological Conditions in Mine Blasting Area

The basic rocks covering the oil shale bed include mainly the groundwater of Keila-Kukruse aquifer. Due to mine dewatering the depression of this aquifer is formed over every working mine, and water level on the oil shale bed varies largely, from 2–5 m in the centre of mines up to 50 m near the perimeter of the mined area (Fig. 1). Water depressions of neighbouring mines are summarized and the groundwater table is temporarily stabilized [1–3]. Dynamic influx into the mine comes from south, and mine dewatering system equalizes it in the deposit centre (Fig. 2). The Quaternary aquifer appears periodically as a table from 0 up to 4 m, depending on precipitation.

The overburden rocks covering the oil shale bed form the vibration medium between mine blasts and endangered objects on the ground surface or under the surface.

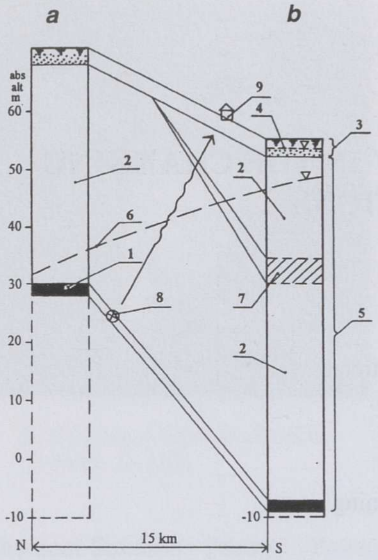

Fig. 1. Hydrogeological section in the area of blast vibration propagation:
a – minimum groundwater table;
b – maximum groundwater table:
1 – oil shale bed;
2 – limestone overburden, basic rocks;
3 – Quaternary sediments;
4 – Quaternary water table;
5 – Keila-Kukruse (groundwater) aquifer;
6 – groundwater table;
7 – relative aquitard;
8 – charges in oil shale bed;
9 – endangered object on the ground surface

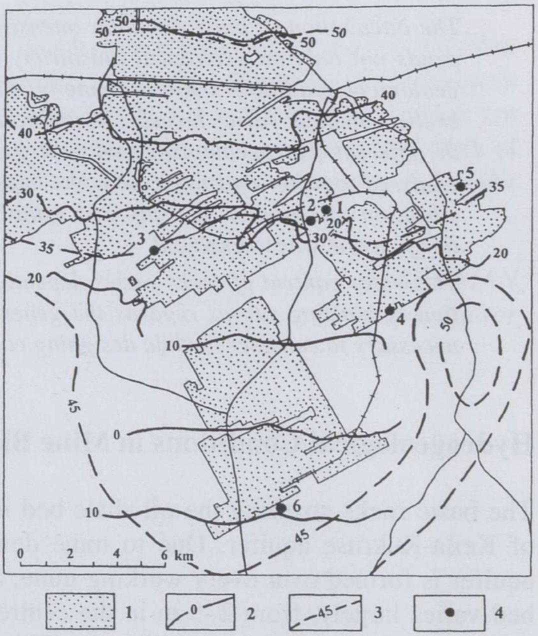

Fig. 2. Mining area with piezometric isolines of groundwater (Keila-Kukruse) in 1996–1998:
1 – mined area;
2 – isolines of the bottom of oil shale bed, m_{abs};
3 – piezometric isolines, m_{abs};
4 – blast vibration measuring sites

In hydrogeological sense the properties of a vibration medium depend on the content of gravity water in joints and planes of discontinuity of rocks. The level of water content has an impact on the vibration velocity and is essential where the vibration danger on the objects on the ground surface is acute.

The ground surface vibration measurements were performed in various geological and hydrogeological situations in various ground and surface water tables. Results are given in Table 1. In the active area of mining, the majority of working faces are hydrogeologically located in an intermediate state, 27–30 % of water content. However, there exist also maximum and minimum conditions.

Table 1. **Hydrogeological Conditions in Blast Vibration Measuring Sites**

Measuring site	Blasting depth, m		Precipitations			Groundwater table		Gravity water content, %	Water content of vibration medium
	absolute	from ground surface	in measuring decade, mm	long-term average of decade, mm	factor	absolute, m	from oil shale bed, m		
1	36	34	54*/0.5	29/24	1.86/0.02	37.5	1.5	4	Minimum
2	32	37	78.6	21	3.7	35	3	8	Minimum
3	22	48	3.1	14	0.22	35	13	27	Intermediate
4	12	51	10.1	14	0.71	31	19	37	Intermediate
5:									
in spring	27.5	20	40*/15	14/24	2.8/0.62	35	7.5	38	Intermediate
in autumn			15	24	0.62				
6	–10	60	3.1	14	0.22	45	55	92	Maximum

* Measuring performed in two decades - 20 days (first decade/second decade).

During the measuring periods (1–10 days) there existed great differences in precipitation, 0.22–3.7 times decade's average. Direct impact of precipitation on the results was not discovered, indirect impact exists in dynamic influx and in the rise of groundwater level, .e. through the total growth of water content of basic rocks.

Vibration Measuring Method

Measuring Sites

Hydrogeological conditions determined the choice of measuring sites. In addition to the intermediate conditions, the extreme sites with maximum and minimum water content were studied.

Measuring Method

Three components of the blast vibration velocity – longitudinal, transversal and vertical ones – and the vector sum were measured. The charges were located in oil shale bed, 20–60 m from the ground surface in different sites. Vibrations were registered on ground surface, and geophone was located in soil, imitating the location of basic walls and shallow underground communications there. The seismographs DS-277 Blast-Mate Series II (Instantel) and UVS 1500 (ABEM Instruments AB) were used. The weights of charges (delay groups) were 12–30 kg and distances between charges and geophones 50–160 m.

To compare the various blasting conditions, the notion of scaled distance d_s was used [4]:

$$d_s = dQ^n (\text{m kg}^{-0.5}) \tag{1}$$

where d is distance between charge and geophone, m;
Q is maximum weight of charge (delay group), kg;
n is exponent, $n = -0.5$.

Thus, the results are comparable concerning different blasting conditions and also comparable with the results of previous measurements.

The Problem of Blasting Depth

The choice of measuring sites was done with the purpose to study various hydrogeological conditions. At the same time these sites were located in different depths from the ground surface. Due to the anisotropic character of the rock properties, the blasting depth was chosen taking into account the results in [5].

Results and Discussion

Special measurements were performed in hydrogeologically extreme conditions, i.e. at maximum and minimum water content of vibration medium; for the following analysis also intermediate conditions were studied and previous data used. Six measurement sites were taken into account in analysis. Every site included 14–33 seismograms, 117 in all. For every measuring site with its hydrogeological conditions the regression equation between maximum vibration velocity and scaled distance was worked out.

The general formula is:

$$V = Ad_s^m \text{ (mm/s)} \tag{2}$$

where V is maximum vibration velocity;
d_s is scaled distance, m kg$^{-0.5}$;
A and m are the empirical parameters of equation.

The results of analysis, empirical parameters and assessment of statistical confidence are given in Table 2. The graphical shape and location of these equations in the log/log field are shown in Fig. 3. These equations characterize the attenuation of vibration velocity in various geological and hydrogeological conditions, numerically expressed by blasting depth (m) and water content of rocks (%).

To make sure the real impact of hydrogeological conditions, it is practical at first to reduce all these equations to the same blasting depths, e.g. to the minimum – 20 m, average – 40 m and maximum depth – 60 m. Using the formulas from [5] demonstrated in Fig. 4, one can see that vibration velocity attenuation is more intensive when d_s = 20 m kg$^{-0.5}$, compared to d_s = = 40 m kg$^{-0.5}$, i.e. more intensive perpendicularly to layering; the more the blasting depth, the more the impact of layering. The proportional factors of vibration velocities were reduced to three blasting depths – 20, 40 and 60 m. After the impact of blasting depth is excluded, the peak particle velocity depends on gravity water content only. In the interval of scaled distance between 20 and 40 m kg$^{-0.5}$, i.e. under the most used blasting conditions, the vibration velocity attenuation is less if gravity water content is high (92 %), and the attenuation is remarkable if water content is low (4 %).

Transforming these functions from the log/log field to the linear one, we get the function:

$$V = f(W) \tag{3}$$

where V is vibration velocity, mm/s;
W is gravity water content of rocks, %.

This function is mathematically described as a linear regression equation:

$$V = AW + B \text{ (mm/s)} \tag{4}$$

where A and B are the empirical parameters of equation.

Table 2. **The Parameters and Statistical Confidence of Regression Equations Between Maximum Vibration Velocity and Scaled Distance**

Measuring site	Gravity water content, %	Number of seismograms	Correlation factor r	Scaled distance d_s, m kg$^{-0.5}$		Parameters of equations			
						m	A		
				minimum	maximum		Equation	90 % lower confidence line	90 % upper confidence line
1	4	14	–0.885	14.1	47.2	–1.53	402	186	886
2	8	19	–0.915	8.4	66.1	–2.484	11114	3470	35,600
3	27	14	–0.947	17.3	78.9	–1.399	307	140	674
4	37	16	–0.852	11.8	64.0	–1.177	84	36	197
5	38	33	–0.581	12.6	65.6	–1.029	261	85	799
6	92	21	–0.913	10.4	80.6	–2.179	3013	1130	8025

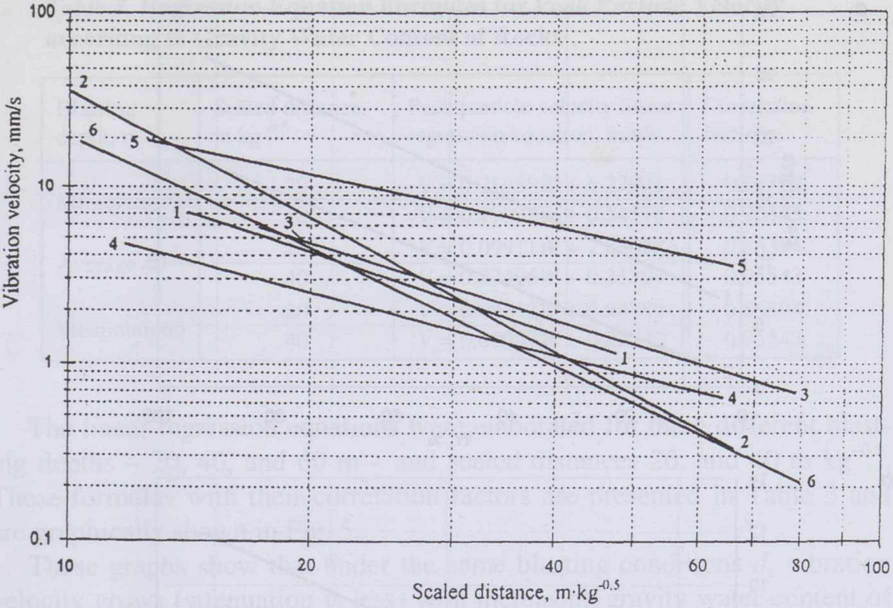

Fig. 3. Ground vibration velocity attenuation at various gravity water content W, %, and in various blasting depth H, m: *1* – $W = 4$, $H = 34$; *2* – $W = 8$, $H = 37$; *3* – $W = 27$, $H = 48$; *4* – $W = 37$, $H = 51$; *5* – $W = 38$, $H = 20$; *6* – $W = 92$, $H = 60$

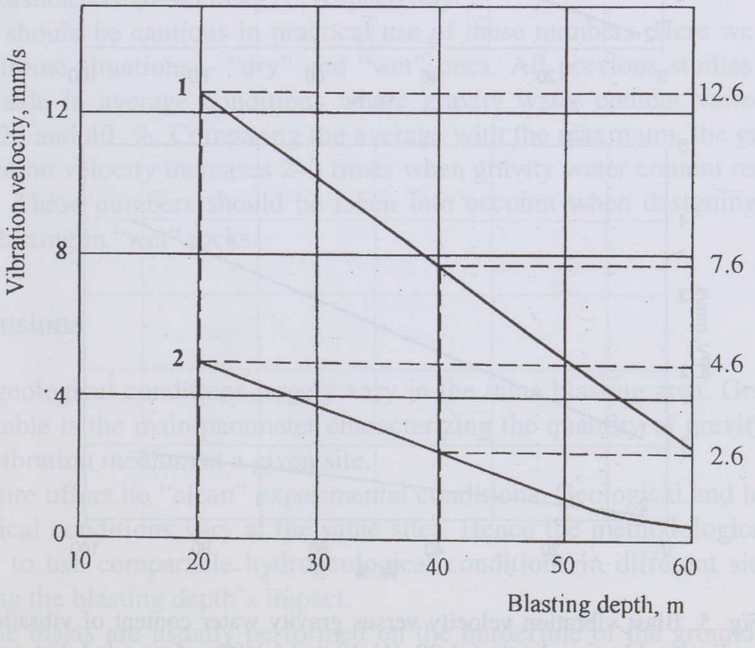

Fig. 4. Variation of blast vibration velocity from blasting depth respectively for scaled distances 20 (*1*) and 40 m kg$^{-0.5}$ (*2*)

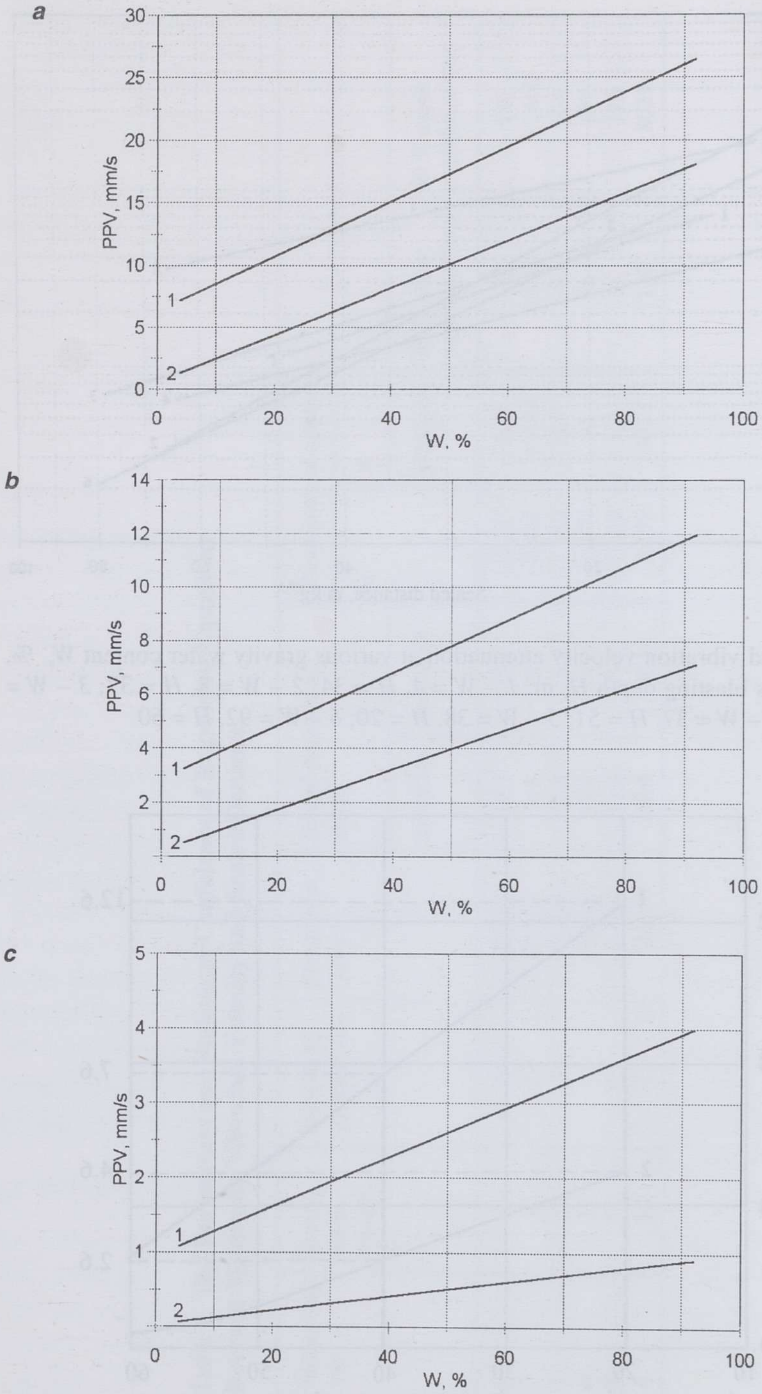

Fig. 5. Blast vibration velocity versus gravity water content of vibration medium in blasting depth: (*a*) 20, (*b*) 40 and (*c*) 60 m for scaled distances 20 (*1*) and 40 m $\mathrm{kg}^{-0.5}$ (*2*)

Table 3. **Regression Equation Formulas for Peak Particle Velocity according to Gravity Water Content of Rocks**

Blasting depth, m	Scaled distance, m $kg^{-0.5}$	Peak particle velocity linear regression equation, mm/s	Correlation factor r
Minimum 20	20	$V = 0.21938W + 6.27903$	0.86398
	40	$V = 0.19032W + 0.54318$	0.95543
Average 40	20	$V = 0.09911W + 2.83658$	0.86394
	40	$V = 0.07496W + 0.21394$	0.95543
Maximum 60	20	$V = 0.03312W + 0.94789$	0.86394
	40	$V = 0.00957W + 0.02732$	0.95543

The linear regression equations were elaborated for three different blasting depths – 20, 40, and 60 m – and scaled distances 20, and 40 m $kg^{-0.5}$. These formulas with their correlation factors are presented in Table 3 and are graphically shown in Fig. 5.

These graphs show that under the same blasting conditions d_s vibration velocity grows (attenuation is less) with increasing gravity water content of rocks. Vibration velocity is higher at the lower numbers of scaled distances, i.e. when charges are greater and distances shorter. It means that the impact of gravity water content grows more in perpendicular direction to layering. The growth of gravity water content from 0 up to 100 % in joints and planes of discontinuity favours the growth of vibration velocity 4–14 times when scaled distance is 20–40 m $kg^{-0.5}$, respectively.

We should be cautious in practical use of these numbers. Here we have two extreme situations – "dry" and "wet" ones. All previous studies have been made in average conditions where gravity water content varied between 25 and 40 %. Comparing the average with the maximum, the growth in vibration velocity increases 2–3 times when gravity water content reaches 100 %. These numbers should be taken into account when designing cautious blasting in "wet" rocks.

Conclusions

Hydrogeological conditions largely vary in the mine blasting area. Groundwater table is the main parameter characterizing the quantity of gravity water in vibration medium at a given site.

Nature offers no "clean" experimental conditions. Geological and hydrogeological conditions vary at the same sites. Hence the methodological necessity to use comparable hydrogeological conditions in different sites so reducing the blasting depth's impact.

Mine blasts are usually performed on the borderline of the groundwater depression, where the gravity water content is 25–40 %. The growth of gravity water content to 100 % increases the vibration velocity 2–3 times, and decreases it 2–4 times at water content 0, while the geological and blasting conditions are the same.

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