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THE IMPACT OF BLASTING DEPTH ON THE INTENSITY OF GROUND VIBRATIONS

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The anisotropic properties of sedimentary overburden rocks, vertical joints and horizontal planes of discontinuity between layers affect the properties of vibration medium. Measurements of vibration velocity for various blasting depths between charges and endangered objects were performed. The growth of the share of blasting depth, i.e. the perpendicular to layers component of distance between charge and object causes a more intensive attenuation of the vibration velocity. The peak particle velocity attenuation as a function of blasting depth for most usable scaled distances was elaborated.

Introduction

Shallow location of oil shale mines causes various impacts of mining processes on the ground surface. Rock blasting in oil shale bed is one of them. In spite of relatively small explosive charges (delay groups), the impact on the ground surface is remarkable. Overburden rocks, covering the oil shale bed and lying between explosive charges and endangered ground surface objects have geologically anisotropic structure, i.e. the properties are different in different directions. The mining depth varies from 20 to 60 m, relatively three times. Therefore, in spite of shallow mining, the changes in the mining depth will have a serious influence on the blast vibration propagation through the overburden rocks and also on the character of the attenuation of intensity of vibration velocity.

Structure and Anisotropy of Vibration Medium

Oil shale bed is covered with sedimentary rocks, mainly limestones and dolomites of stratified structure, lying almost horizontally, with light slope (0,3 %) in southern direction. In the same direction the depth of oil shale bed is growing, from 20 to 60 m in the area of closed and working mines.

Overburden is intersected by vertical and subvertical joints of tectonic origin, mainly in NW and NE directions. Vertical joints are studied in details; their occurrence and statistical data are determined in the depth 20-40 m [1-3]. Additionally to vertical joints, there exists the system of horizontal weak contacts (planes of discontinuity). These contacts are located irregularly. To the depth of 40 m, there exist two main zones of horizontal weak contacts, favoring the horizontal filtration of ground water.

The system of vertical joints and horizontal weak contacts is shown in Fig. 1. In the depth of 50 m, there is a third zone of horizontal contacts. Statistically average distance between vertical NW joints is 28 m and between NE joints 130 m. The distance between horizontal weak contacts varies between 0.2-5 m [1, 3]. The last numbers show the large variation of distances between weak contacts. Taking the maximum average distance - 5 m, the ratio to the distances of NW vertical joints is 5.5 and NE joints - 26. These ratios show the block-structure of overburden, the average size of blocks is 130 × 28 × (0.2-5) m. Such structure of overburden causes different properties of rocks on different directions, i.e. the anisotropy of the blast vibration medium.

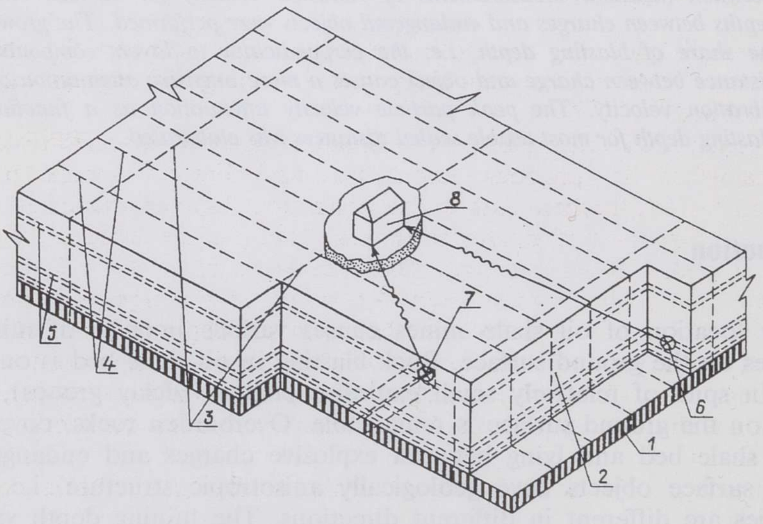

Fig. 1. The idealized chart of the discontinuity of vibration medium (without soil cover): *1* - oil shale bed; *2* - overburden of sedimentary rocks; *3* - NE joints; *4* - NW joints; *5* - horizontal weak contacts (planes of discontinuity); *6* - opencast blast; *7* - underground blast; *8* - endangered object

Blasting and Ground Vibration Measurement Conditions

The explosive charges were located in oil shale bed, geophone was located in the soil on the ground surface and also in mine workings in oil shale bed modelling the possible placing of endangered objects. The blast vibrations were measured in sites where the depth between charges and geophone varied between 20 and 50 m, i.e. in real conditions of underground mining. The shot method of blasting is used in mines, therefore the charge weight means the weight of explosive in one delay group. One delay group is the group of shots spaced on a certain area and initiated simultaneously. The weight of delay groups varied from 3.6 kg (4 shots) until 36.0 kg (40 shots), consequently the sizes of delay groups varied from concentrated charges until dispersed ones with growing the total weight of charges. The explosives ammonite and nobelite were used, their properties did not differ essentially.

The horizontal distance between charges and geophone varied from the epicentre of the delay group up to 200 m. The choice of various distances was necessary to get the measurement data for a wider area of scaled distance, and for better function between vibration velocity and scaled distance. The main attention was paid to shorter distances, to make sure the impact of blasting depth (vertical distance) on the attenuation of vibration intensity. At the same time the preciseness of determination for shorter distances is falling due to dispersed charges in the delay group. Generally, the measurements were carried out for ordinary, everyday conditions of blasting practice in mines.

Discussing of Results

The scaled distance will remain an important link between the charge weights and distances between charges and endangered objects on the ground surface.

The general relationship between vibration velocity and scaled distance was established in previous researches on vibration media under discussion in [4, 5], where mainly the horizontal distance was taken into account. In the cases of greater horizontal distances the share of vertical distance (depth) is not essential. These cases usually satisfy the safety conditions in opencast mining and also partly in underground mining. However, there are cases, where the growing depth of mining and possibility of varying of delay group weight enables to approach safely close under the surface objects. There will appear a tempting opportunity of moving with working faces (and with blasting) through the footing of a surface object.

For mining conditions in an oil shale deposit the suitable scaled distance is

$$d_s = \frac{d}{\sqrt{Q}} \quad (\mathrm{m \cdot kg^{-0.5}}) \tag{1}$$

where d is the distance between explosive charge and object;

Q is the weight of charges in the delay group.

The pertinence of this notion was proved in [4, 5].

The study of mining depth's impact on vibration velocity means that we should have measurement data in short horizontal distances between explosive charges and geophone (object). At the same time it is complicated to determine the exact distance between charges and geophone, especially when there are greater delay groups. The shorter the distance and the greater the delay group, i.e. the more dangerous conditions for protected objects, the less the scaled distance. Taking maximum charge weight 36 kg and the distance 50-200 m, we have scaled distances for mines 8-33 $m \cdot kg^{-0.5}$. Comparing with opencast, where the maximum charge weight is usually about 2500 kg, distances from 400 m (flyrock condition) up to 2500 m (real objects), there were the same numbers of scaled distances. Practical field measurements were carried out in the area 15-80 $m \cdot kg^{-0.5}$. In the area less than 15 $m \cdot kg^{-0.5}$, the precision of measurements dropped down. One of the causes may be the scattered character of bigger delay groups (dispersed charges).

To establish the correlation between blasting depth and vibration velocity, the notion of scaled distance is necessary. When blasting front approaches the endangered object, the share of vibration medium properties in horizontal direction decreases and the share of the vertical component grows. Thereby, generally the vibration velocity is a function of scaled distance and blasting depth.

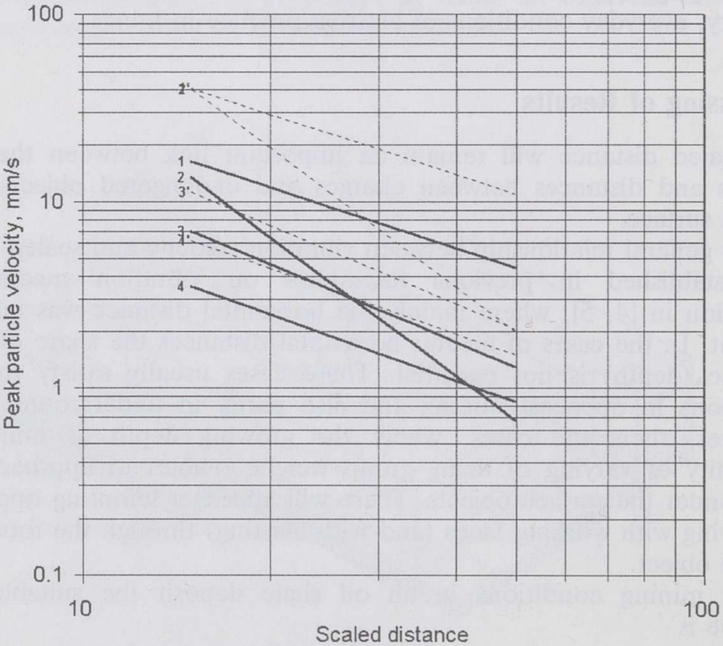

Fig. 2. Variation of peak particle velocities depending on scaled distances according to experimental data: *1, 2, 3,* and *4* - for blasting depths 20, 37, 48, and 51 m, respectively, statistical with 95 % upper confidence lines *1', 2', 3',* and *4'*

The instrumental measurements of vibration velocity were performed in the interval 20-50 m of blasting depths. Regression formulas were elaborated for the depths 20, 37, 48, and 51 m, where the number of measurements were 33, 19, 14, and 16, respectively, with the correlation factor between scaled distances and peak particle velocities -0.65, -0.91, -0.95, and -0.89. The graphical shapes of formulas (average and 95 % upper confidence lines) are shown in Fig. 2.

On the log/log field one can see that the growth of blasting depth from 20 to 51 m causes the decrease in vibration velocity 4.8 times at the scaled distance 20 $m \cdot kg^{-0.5}$, and 5.3 times at the scaled distance 50 $m \cdot kg^{-0.5}$. The measurements for every blasting depth were made in different sites, generally in the similar geological conditions, but there may be differences in details (joints, variety of horizontal weak contacts). Therefore one should continuously assess the initial data, taking into account their statistical confidence limits. Regardless of these limits, the tendency of decreasing the peak particle velocity together with the growth of the share of blasting depth within the scaled distance are evident.

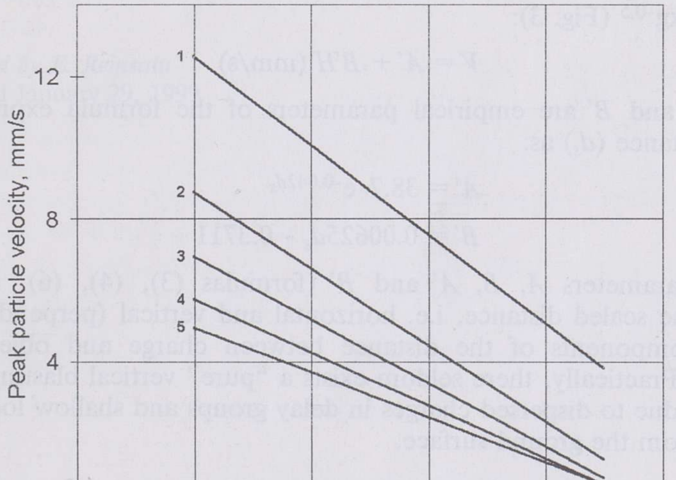

Fig. 3. Variation of peak particle velocities depending on blasting depth: *1*, *2*, *3*, *4*, and *5* - scaled distances 20, 25, 30, 35, and 40 $m \cdot kg^{-0.5}$, respectively

The general equation for peak particle velocity attenuation as a function of blasting depth is

$$V = A \cdot H^B - 50 \text{ (mm/s)} \quad (2)$$

where H is blasting depth, m;

A and B are empirical parameters of the formula (2), expressed by scaled distance (d_s) as

$$A = 149.48 \cdot e^{-0.01306 d_s} \quad (3)$$

and

$$B = 0.0029 d_s - 0.1746 \quad (4)$$

The values of A and B for scaled distances 20-40 $m \cdot kg^{-0.5}$ are given in the Table.

Empirical Parameters for Formulas (2) and (5)

Scaled distance d_s, $m \cdot kg^{-0.5}$	A	B	A'	B'
20	118.7	-0.1214	17.58	-0.2501
25	106.05	-0.0977	13.04	-0.2144
30	98.81	-0.0814	10.51	-0.1777
35	93.97	-0.0704	8.73	-0.1488
40	90.51	-0.0617	7.50	-0.1266

According to Eq. (2), the function curves approach the abscissa. For blasting depth 20-60 m, the vibration velocity attenuation equation may be taken for practical use in the form (5), i.e. linear for scaled distances 20-40 $m \cdot kg^{-0.5}$ (Fig. 3):

$$V = A' + B'H \text{ (mm/s)} \quad (5)$$

where A' and B' are empirical parameters of the formula expressed by scaled distance (d_s) as:

$$A' = 38.7 \cdot e^{-0.042 d_s} \quad (6)$$

$$B' = 0.00625 d_s - 0.3711 \quad (7)$$

The parameters A, B, A' and B' (formulas (3), (4), (6), and (7)) include the scaled distance, i.e. horizontal and vertical (perpendicular to seams) components of the distance between charge and object taken together. Practically, there seldom exists a "pure" vertical blasting impact direction due to dispersed charges in delay groups and shallow location of charges from the ground surface.

Conclusions

In horizontally laying sedimentary rocks the blast vibration velocity attenuation in the vertical direction, perpendicular to strata is more intensive than in the horizontal direction. This widely known fact enables to diminish the impact of underground blasting on the objects located on the earth surface.

The closer the charges located under the epicentre on the ground surface, where the endangered object is located, i.e. the greater the share of the vertical component of the distance, the more intensive the attenuation of vibration velocity, when other blasting conditions are constant. The pertinent function has been elaborated for blasting depth 20-50 meters and scaled distances 20-40 $m \cdot kg^{-0.5}$.

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