ENVIRONMENTAL IMPACT OF MINE BLASTING

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ABSTRACT *The blasting is the predominating method of breaking rocks in various surface and underground mines. At the same time some damaging impacts on environment are evident: noise, gas, dust, flyrock and ground vibration. The last factor is most important for safety of constructions, buildings and various natural objects in the vicinity of mining area. The ground vibration parameters, crucial for safety of endangered objects have a significant correlation with charge weight and distance of blasting. The properties of vibration medium impact on the value of these parameters. This study tried to associate the main vibration parameter, particle velocity with blasting parameters and properties of vibration medium. The blast vibrations were studied in the soil of Quaternary sediments and in Ordovician limestone in Estonian oil shale mining area in opencast and underground mines. The analysis of measured data pointed significant correlation between vibration velocity and scaled distance from charges. The formulas and nomographs for prediction of vibration velocity and for maximum permitted charge weights were elaborated for basic rocks and for soil, for oil shale underground and opencast mines. Using these formulas and nomographs in blast design will make possible to diminish the impact of mine blasting on the objects located in the vicinity of mining area.*

Introduction

The blasting is the predominating method of breaking rocks in various underground and opencast mines due to the rational use of destructive energy. At the same time some negative impacts on environment are evident: noise, gas, dust, flyrock and ground vibration. The last factor is most important for safety of constructions, buildings and various natural objects like water-bodies and aquifers in the vicinity of mining area. The blasting is widely used in both oil shale underground and surface mining in Estonia. One of oil shale opencasts - Aidu and most of the underground oil shale mines are surrounded by densely settled rural area.

The ground vibration parameters, crucial for safety of constructions have a significant correlation with charge weight and distance of blasting. The properties of vibration medium also impact on the value of vibration parameters. This study tried to associate the main vibration parameter, particle velocity with blasting parameters and properties of vibration medium.

1. Blasting Conditions

The mineable oil shale seam is covered with Ordovician limestone and dolomites, Quaternary sand and moraine (Table 1).

ISBN - 9984-585-55 -7

Table 1

Blast vibration media in Aidu oil shale opencast

Rock	Thickness, m	Density, Mg/m^3	Compressive Strength, MPa	Wave propagation velocity, m/s
Sand, moraine	4	1.6 - 1.9		1000 - 1500
Limestone, dolomite	12 - 13	2.5 - 2.7	40 - 70	1600 - 2500
Oil shale	2.8 - 3.0	1.3 - 1.8	20 - 30	700 - 1300

In oil shale surface mining after the soil removal overburden rocks will be prepared for excavation by blasting. After overburden excavation the next - oil shale bench will be prepared for excavation with blasting. The main ground vibration impact is caused by overburden blasting (Fig. 1).

In oil shale surface mining the following explosives are used: Grammonite, ANFO and Ammonite. The diameter of blastholes is 115 and 243 mm; hole spacing 6-7 m and depth 12-13 m. The specific charge of explosives is 0.7-0.9 kg/m^3. Traditionally for initiation the detonating cord system with detonation relays is used, with detonating cord and primer in blastholes. In 1996 the using of non-electric blasting caps (Dynashock) was started in Narva and Aidu opencast mines.

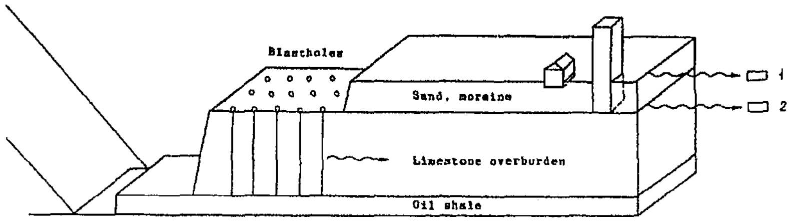

Figure 1. Ground vibration measurements of overburden blast in oil shale surface mining:
1 - geophone on the soil, 2 - geophone on the overburden.

In oil shale underground mining the blasting is used for breaking the mineable oil shale seam in working faces of all development headings and in room-and-pillar mining, the predominating method in oil shale mines. In oil shale underground mining the thickness of mineable oil shale seam is 2.8 - 3.0 m, and it is covered with Ordovician limestone and dolomites with thickness 20-50 m. The soil, covering limestone, contains sand, moraine and sporadically loamy intercalations has the thickness from 2-10 metres. Consequently the blast waves will pass the limestone and soil to reach the objects on ground surface. The possible underground objects are placed in the same limestone overburden or even below it (Fig. 2).

In underground mining the Ammonite and (since 1998) Nobelite is generally used. In oil shale underground mining the shot method is in use, every shot has usually a charge 0.6-0.9 kg ammonite in cartridges with average specific charge about 0.7-0.8 kg/m^3. In short-delay blasting the weight of delay groups vary among 2-36 kg. The total weight of delay group depends on the number of simultaneously blasted faces.

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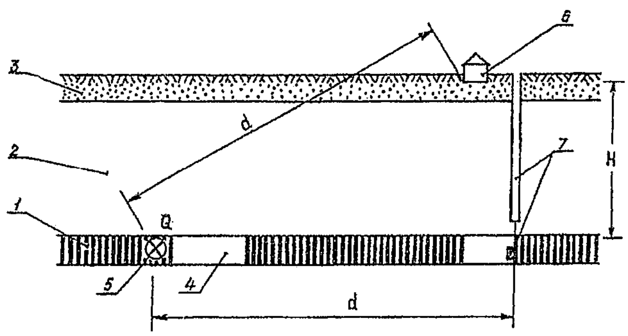

Figure 2. Vibration measurements of underground blasting:
1 - mineable seam, *2* - limestone overburden. *3* - soil, *4* - mine working, *5* - charge (Q), *6* - geophone in soil, *7* - geophone in basic rocks

2. Vibration measurements

The measurements were performed by seismograph DS-277 BlastMate Series II of Instantel Inc. and seismograph UVS - 1500 of ABEM Instruments AB in Estonian oil shale opencast and underground mines.

The intensity of ground vibrations was measured through the velocity of individual particles of rocks during their oscillatory motion. The velocity has been determined to be the most important parameter to assess the blast damage [1, 2, and 3].

The time-histories of studied blasts were recorded by seismographs. Three components of vibration velocity - transversal (V_T), vertical (V_V), and longitudinal (V_L) were measured. The peak component varied with each blasting and time history record of vibrations pointed the presence of many peaks. The peaks of different components occur at different time and the maximum vector sum (V_{VS}) of these components as a maximum possible vibration velocity was used in following study.

$$V_{VS} = \sqrt{V_T^2 + V_V^2 + V_L^2} \qquad (1)$$

In oil shale surface mining the preliminary regression analysis between the scaled distance and vibration velocity pointed the difference between velocities at the same scaled distances in different vibration media - in soil and in overburden limestone. The sequence analyse of vibration velocity was performed separately for soil and limestone [4].

In oil shale underground mining the preliminary study of peak particle velocity (PPV) function showed that the influence of the thickness horizontally laying sedimentary rocks has the remarkable impact on the attenuation of ground vibration. This matter caused to group the data according to levels between the locations of charge and objects of interest. Three cases were chosen [5]:

1. Blasting in oil-shale seam, measuring in basic rocks-limestone at the same level, H = 0 m;
2. Blasting in oil-shale seam, measuring in soil (ground surface), H = 20 m; i.e. minimum depth of underground mining;
3. Blasting in oil-shale seam, measuring in soil, H = 50 m; i.e. the depth of most cases of underground mining.

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3. The prediction of peak particle velocity (PPV)

The attenuation of seismic waves depends on properties of explosive and vibration medium. When the properties of explosives are similar, the properties of medium are of cardinal importance. Vibration velocity in the point of interest depends on the weight of charge or delay group (Q), distance of blasting (d) and properties of vibration medium. Generally the parameters vary and for comparing the various blasting situations the motion of scaled distance (d_s) is widely in use [2 and 3].

$$d_s = d \cdot Q^n, \tag{2}$$

In this equation the exponent n = -1/3...-1/2 is used in vibration prediction practice. According to [3] the more conservative results gives n = -1/3, when d<6 m and n = -1/2, when d>31 m. The both exponents may be in use, when 6 < d < 31 m.

The points of interest in oil shale both surface and underground mining are over 31 m distance, the fixed objects and constructions are located away from blasting site. Therefore in this case the square root is used, to determine the scaled distance.

$$d_s = \frac{d}{\sqrt{Q}} \tag{3}$$

A plot of peak particle velocity versus scaled distance is a complex curved line on linear graph paper. To show this relationship as a straight line, and to compress a wide range of values onto a single sheet, the plot is made in logarithmic co-ordinates (fig.3). The slope of the curve shows that as the scaled distance increases, the vibration velocity decreases.

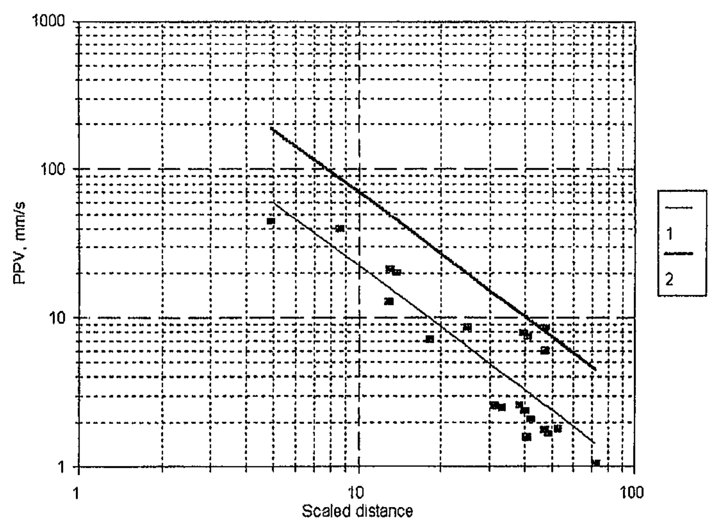

Figure 3. Variation of peak particle velocities in basic rocks of limestone on blasting level (H=0): *1* - regression equation line, *2* - upper 95% confidence line.

The collected data points are input to the regression analysis calculation. The resultant equation is for a geometric curve in the form:

$$v = a d_s^b \text{, mm/s} \tag{4}$$

Where *a* and *b* are the regression equation constant and coefficient.

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In oil shale **surface mining** were recorded 20 blast time-histories in soil and 26 blast time-histories in basic rocks. In oil shale **underground mining** were recorded in soil (ground surface) in blasting depth 20 m - 33 blast time-histories; in blasting depth 50 m - 30 blast time-histories; and in basic rocks, at blasting level 21 blast time-histories. The regression equations for prediction the vibration velocities and their upper 95% confidence lines formulas were presented in table 2.

Table 2

Equations for prediction of the vibration velocity

Blasting situation	Location of geophone	vibration velocity, (mm/s)	
		regression equation formula	upper 95% confidence line formula
Surface blasting	soil	$v = 3090d_s^{-2,03}$	$v = 10600d_s^{-2,03}$
	basic rocks	$v = 137d_s^{-1,08}$	$v = 374d_s^{-1,08}$
Underground blasting	soil; blasting depth 20 m	$v = 300d_s^{-1,08}$	$v = 896d_s^{-1,08}$
	soil; blasting depth 50 m	$v = 136d_s^{-1,25}$	$v = 309d_s^{-1,25}$
	basic rocks; blasting at the same level	$v = 560d_s^{-1,25}$	$v = 1748d_s^{-1,25}$

These equations and their 95% upper confidence line formulas (table 2) may be used for prediction of peak particle velocity for various charge weights and distances of blasting from interested objects. The additional conditions of vibration media, horizontally jointed sedimentary rocks essentially weakens the intensity of PPV, consequently the depth of blasting will be taken into account.

4. Charge weight limits

If the predicted peak particle velocity will exceed the certain standard of velocity for the interested object, the charge weight limit should be established. After transforming the regression equations (table 2) and using their 95% upper confidence line formulas, the formulas of maximum permitted charges are elaborated [4 and 5].

In oil shale surface mining for objects, placed in soil, the maximum permitted weight is:

$$Q = \left(\frac{d}{\left(\frac{11450}{v_{conc}} \right)^{0.49}} \right)^2 \text{, kg} \tag{5}$$

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where v_{conc} is the conceded vibration velocity and d is distance of charge from interested object.
For objects, placed on overburden limestone, the maximum weight is:

$$Q=\left(\frac{d}{\left(\frac{374}{v_{conc}}\right)^{0.93}}\right)^{2}, \text{ kg} \tag{6}$$

In oil shale underground mining for objects, placed in basic rocks, in limestone at the level of blasting, the maximum permitted charge weight is:

$$Q=\left(\frac{d}{\left(\frac{1748}{V_{conc}}\right)^{0.718}}\right)^{2} \text{ (kg)}, \tag{7}$$

For objects, placed in soil on ground surface, when blasting depth is 20 m, maximum permitted charge weight is:

$$Q=\left(\frac{d}{\left(\frac{896}{v_{conc}}\right)^{0.929}}\right)^{2} \text{ (kg)} \tag{8}$$

For object, placed in soil on ground surface, when blasting depth is 50 m, maximum permitted charge weight is:

$$Q=\left(\frac{d}{\left(\frac{309}{V_{conc}}\right)^{0.803}}\right)^{2} \text{ (kg)} \tag{9}$$

Nomograph on Fig. 4 demonstrate the variation of permitted charge weight from distance of blasting and permitted vibration velocity for endangered object according to existing vibration standard.

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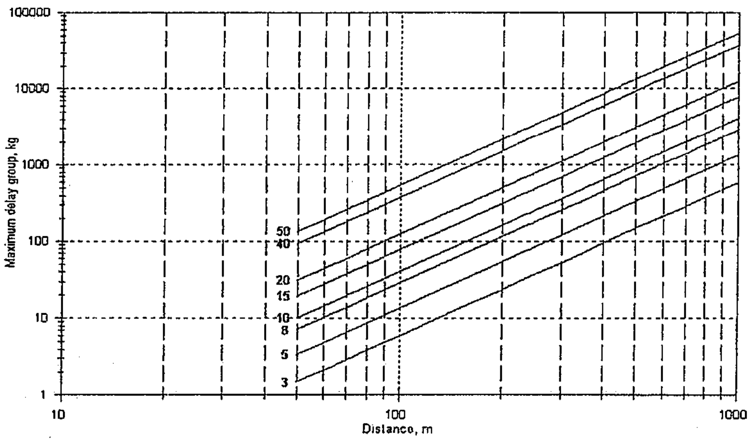

Figure 4. Charge weight-limiting nomograph for soil, blasting depth H=50 m: given (permitted) velocities 3, 5, 8, 10, 15, 20, 40 and 50 mm/s

Conclusions

In oil shale surface and underground mining a significant correlation between the ground vibration velocity and the scaled distance enables to predict the vibration velocity in the rocks of oil shale mining area (and in analogous geological conditions). The seismically safe blast design is possible using the elaborated regression formulas and nomographs.

In oil shale underground mining the data analyse pointed very intensive vibration decay in vertical direction, transversely to overburden strata in comparing with horizontal direction. For later planning of safety blasting more exact decay function from depth is necessary, and consequently the field study data for intermediate depths.

The variety of geological properties of seams of sedimentary rocks, the joints and the karst phenomena in overburden rocks have an impact on vibration parameters. The hydro-geological conditions also may have an influence on these parameters. The impact of variable geological and hydro-geological conditions on vibration parameters needs more detailed researches. In this study the average properties of vibration medium are taken account with statistical analysis of empirical data.

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