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RETROSPECTIVE ENVIRONMENTAL ASSESSMENT OF BLAST VIBRATION IMPACT IN UNDERGROUND MINING

A. TOOMIK

Tallinn University of Educational Sciences,
Institute of Ecology,
North-East Estonian Department
15 Pargi St., Jõhvi 41537, Estonia

The blast vibration impact on the ground surface objects is usually expected to be smaller in underground mining, comparing with surface mining due to less charges. In the case of shallow mines blast vibration velocity may exceed permissible values when mining faces move closely under surface constructions. Long period of mining, 40-50 years, is accompanied by variation in mining and blasting methods, geological conditions and also safety regulations. At mine closing, it is, among the other technological factors, also necessary to assess the blast vibration impact on the environment. As an example of after-effect study, the recently closed Ahtme mining field in Estonia oil shale deposit was used.

Introduction

In oil shale mines of North-East Estonia the depth of bedding is 20–60 m from the ground surface. According to the previous investigations [1], in some cases the blast vibration may damage surface constructions.

As an example of the retrospective environmental assessment, the conditions of the recently closed *Ahtme* mining field were studied. Its mining and blasting depth varied from 20 to 55 m. Ordovician limestone overburden is covered by 2-3 m of Quaternary sediments. Through this vibration medium the blast waves reached the basements of constructions on the ground surface. During mining, when blasting was performed in the periphery of the mining field periodically, groundwater filled 90 % (usually 25–40 %) of overburden rocks. Water content of rocks favors better blast wave propagation [2], and in every single case this percentage should be taken into account.

Attenuation of vibration intensity is different in vertical (perpendicularly to bedding) and horizontal directions. Geological anisotropy diminishes vibration intensity more in vertical direction. Constructions located in the area of blasting, above the blasting sites in mine, are the most endangered objects on the ground surface.

Intensity of Blast Vibration

The experimental study of vibration medium was performed for concrete geological conditions of the *Ahtme* mine. The function of blast vibration velocity attenuation is established for two extreme cases, for blasting depths 20 and 50 m [1].

For the blasting depth 20 m the medium vibration velocity (V, mm/s) was expressed by scaled distance (d_s, $m \cdot kg^{-0.5}$) as follows:

$$V = 300 \cdot d_s^{-1.077} \tag{1}$$

and for the 95-% upper confidence line

$$V_{95} = 896 \cdot d_s^{-1.077} \tag{2}$$

Scaled distance is expressed as follows:

$$d_s = d \cdot Q^{-0.5} \tag{3}$$

where d is distance between charge and object, m;
Q is mass of charge or delay group, kg.

Using the notion of scaled distance it is possible to compare the results of blasting with different charge masses and at different distances from endangered objects.

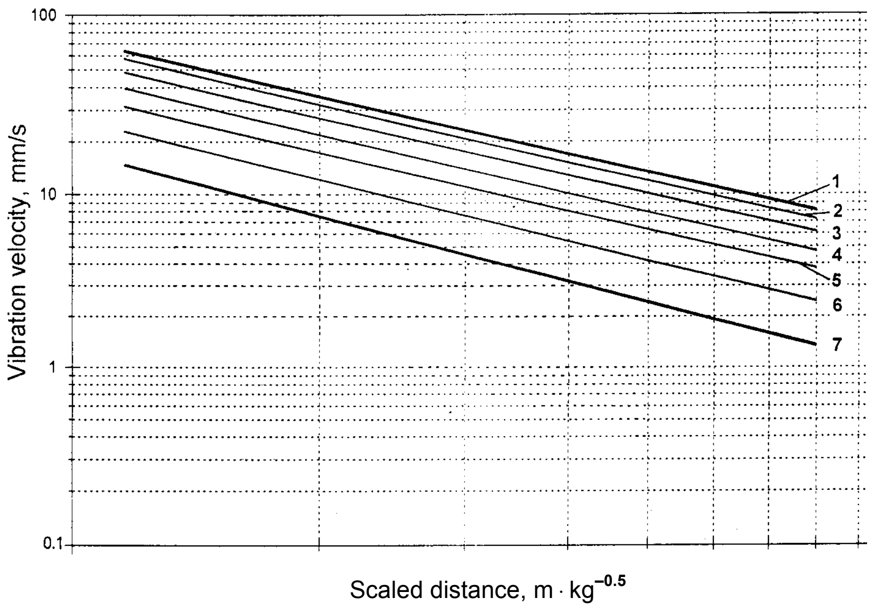

Fig. 1. The 95-% upper statistical confidence lines of blast vibration velocity attenuation: *1* and *7* – experimental graphs for blasting depths 20 and 50 m, respectively; *2*, *3*, *4*, *5* and *6* – interpolated for depths 25, 30, 35, 40 and 45 m, respectively

For the blasting depth 50 m the vibration velocity equations are

$$V = 136 \cdot d_s^{-1.243} \tag{4}$$

and

$$V_{95} = 309 \cdot d_s^{-1.246} \tag{5}$$

To assess blasting safety for a surface object it is necessary to use the statistical 95-% upper confidence line of experimental data. For various blasting depths the extreme values were extrapolated, and the graphs are shown in Fig. 1. For concrete conditions the charge mass, distance from the endangered object and vibration velocity are functionally related.

Studying the blasting situation of a certain site and time in mining history, it is possible to calculate the scaled distance according to Formula (3). It requires exact knowledge of used charge weights. After that, using the Formulae (2) or (5) or graphs in Fig. 1, it is possible to establish the value of blast vibration velocity. The established value of vibration velocity should be compared with the one permitted by regulations of this time for endangered objects of this site.

Mining and Blasting Methods

During first two decades of exploration in the *Ahtme* mine the longwall mining method with rock blasting in faces was used. Rock blasting was also used in preparatory workings. Mining faces located in NE part of the mining field, 20–30 m from the ground surface. Fuse ignition was used, the mass of one shot was 0.8 kg, 5-6 shots in one group, which should be blasted almost simultaneously according to the equal length of fuses.

Some irregularity in fuse combustion diminished the probability of simultaneous blasting of these shots as one seismic impulse (during 50 ms), maximally two charges, i.e. 2 × 0.8 = 1.6 kg would blast simultaneously. At the same time in preparatory workings the charges 0.8–1.4 kg were used [3]. The amount of charges in these faces as well as possibilities of blast impulse coincidence were less.

Table 1. **Blasting Methods and Charges**

	Period	
	1947–1965	1965–1999
Mining method	Longwall	Room-and-pillar
Blasting ignition	Fuse ignition	Electric firing
Charge weight, kg	1.6 and 1.4 for drifting (preparatory works)	4.5; 7.2 (and multiple) and 6.3 for drifting

In the middle of the 1960s the room-and-pillar method was introduced, and electric firing was put to use for blasting. This method enlarged possibilities to form greater charge groups in faces. According to archive documents, the delay groups of charges were 4.5 and 7.2 kg usually. Far from endangered objects the delay groups of 14, 22 and 36 kg were used, i.e. the groups 4.5 or 7.2 kg were formed. Approaching endangered objects the groups were diminished to 4.5 or 7.2 kg. Blasting methods and charges used are summarized in Table 1.

Seismically Endangered Area on the Mining Field

The mass of charges (shots) used in a mine is less than that used in opencast mining, hence the blast vibration impact should be smaller. At the same time the blasting depth, i.e. distance to the objects on the ground surface is small. Mining faces usually moved closely to the vertical projection of the surface object or to the pillar supporting this object, and sometime the face could pass under the object, undermining it. In this maximum case the safe distance becomes the safe depth of mining in seismic sense.

Proceeding from charge weights used in mine (Table 1) and calculated vibration velocities (Formulae (2), (5) and Fig. 1) for concrete situations, the review about possible blast vibration impact on the ground surface of the mining field is composed (Table 2).

Considering the mining and blasting methods used and the regulations valid for the time, it is possible to evaluate mining (and blasting) depths, where undermining of surface objects could exceed standards, i.e. to determine seismically dangerous zones on ground surface. For the *Ahtme* mining field they are plotted in Fig. 2.

Table 2. **Calculated Vibration Velocities in the Epicenter of Blasting Site**

Indices	Blasting depth, m								
	20	25	30	35		40		45	50
Longwall, fuse ignition									
Charge, kg	1.6							–	
Scaled distance, $m \cdot kg^{-0.5}$	16	20	24	28		32		–	
Calculated vibration velocity, mm/s	35	30	18	15		11		–	
Room-and-pillar mining, electric firing									
Charge, kg	–	4.5		7.2	4.5	7.2	4.5	4.5	
Scaled distance, $m \cdot kg^{-0.5}$	–	11	14	13	16	15	19	21	24
Calculated vibration velocity, mm/s	–	65	40	35	30	22	17	12	5
Drifting, electric firing									
Charge, kg	6.3								
Scaled distance, $m \cdot kg^{-0.5}$	8	10	12	14		16		18	20
Calculated vibration velocity, mm/s	80	65	50	37		25		15	7

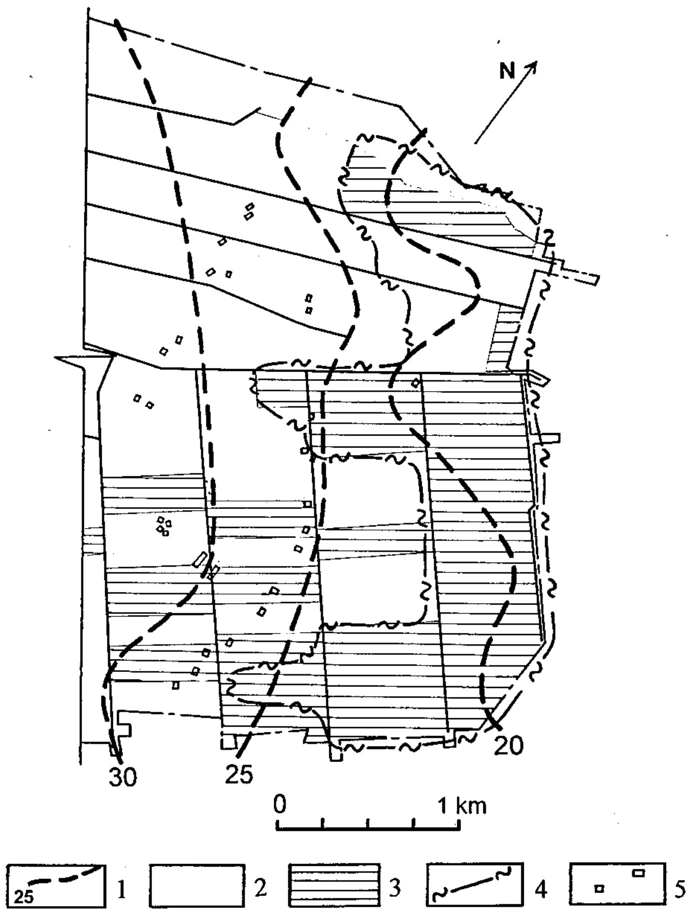

Fig. 2. Seismically endangered area in the north-eastern part of the *Ahtme* mining field: *1* – isoline of blasting depth, m; *2* – the area of longwall mining; *3* – the area of room-and-pillar mining; *4* – seismically endangered area, *5* – dwelling houses on ground surface

Table 3. **Permitted Maximum Vibration Velocities* for Constructions in Soil (Sand, Moraine)**

Indices	Endangered object								
	Construction of light-weight concrete blocks			Brickhouse			Wooden house		
	Distance between object and charge, m								
	20	30	50	20	30	50	20	30	50
Permitted velocity, V_1, cm/s	1.5	1.4	1.2	1.5	1.4	1.2	1.5	1.4	1.2
Correction factor of construction, F_k	0.75			1.00			1.20		
Permitted maximum vibration velocity, V_{max}, cm/s	1.12	1.05	0.9	1.5	1.4	1.2	1.8	1.7	1.4

* Calculated according to [4].

Seismically safe distances depend also on regulations, valid in the time we are interested in. After 30.11.1999, safe distances are determined according to [4] in Estonia. New standard is more rigorous, e.g. the maximum permitted vibration velocity for wooden houses is 14–18 mm/s. For more sensitive houses permitted vibration velocity is ~10 mm/s (Table 3).

Comparison of Tables 2 and 3 reveals that:

- in longwall faces of the *Ahtme* mine, where fuse ignition was used, the blast vibration did not exceed the standard of that time (30 mm/s);
- when room-and-pillar mining with electric firing was used, the blast vibration exceeded the previous standard (30 mm/s) in depths less than 35 m and the new standard in depths less than 45 m;
- in faces of preparatory workings the safe blasting depth began from 38-40 m according to the previous standard (30 mm/s) and 45 m according to the new one, when the maximum charge weight was 6.3 kg.

In seismic sense, mine workings do not approach the town of Ahtme dangerously, but they represent danger to detached country houses in the North-Eastern part of the mining field.

Conclusions

1. Blast vibration impact on the ground surface objects depends on the mass of simultaneously blasted charges and on the distance (depth) of the objects from charges. During mining works in the *Ahtme* mining field different blasting methods (and charges) in different blasting depths were used.
2. Seismically endangered areas for objects on the ground surface are those where blast vibration velocity exceeds its permitted value. In the case of longwall mining with fuse ignition, the safe blasting depth exceeded 20 m, and for room-and-pillar mining with electric firing – 40 m.
3. The endangered blast vibration area is located in the North-Eastern part of the *Ahtme* mining field. Close to this area six dwelling houses are located. One of them may be directly damaged when preparatory working face moves close. “Doubtful” houses need a detailed study of the state of construction.
4. To have confident initial data for assessment it is necessary to know the function of blast vibration velocity attenuation for concrete geological conditions. It is possible to carry out additional field studies or to use the data of an analogous vibration medium. It is possible, according to archive documents, to restore blasting situations and used charged weights.

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