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BLAST VIBRATIONS IN OIL SHALE SURFACE MINING

A. TOOMIK
Institute of Ecology,
North-East Estonian Department
Pargi 15, Jõhvi EE2045, Estonia

T. TOMBERG
Tallinn Technical University,
Mining Institute
Kopli 82, Tallinn EE0004, Estonia

The blast vibrations were studied in the soil of quaternary sediments and in Ordovician limestone in mining area. The measurements were performed by seismograph DS-277 Blast-Mate Series II of Instantel Inc. and seismograph UVS-1500 of ABEM Instruments AB. The analysis of measured data pointed at a good correlation between vibration velocity and scaled distance from charges. The formulas for prediction of vibration velocity and for maximum charge weights were elaborated for both vibration media - soil and limestone.

Introduction

Blasting as a method of rock loosening and destruction in oil shale surface and underground mining will be applied in future, too, 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 and buildings in the vicinity of mining area. One of oil shale open pits - *Aidu* is located in the western part of the Estonian oil shale deposit and is surrounded by densely settled rural area.

The ground vibration parameters, crucial for safety of constructions have a good correlation with charge weight and distance of blasting as proved by many authors in various countries. There is a problem with vibration medium. The properties of medium impact on the value of these parameters. This study tries to associate the main vibration parameter, particle velocity, with blasting parameters and properties of vibration medium.

1. Rock Blasting and Vibration Medium

The mineable oil shale seam is covered with Ordovician limestones and dolomites, Quaternary sand and moraine (Table 1). After the soil removal overburden rocks will also be prepared for excavation by blasting. After overburden excavation the next - oil shale bench will be prepared for excavation with blasting. Then main ground vibration impact is caused by overburden blasting (Fig. 1). For limestone crushing the following explosives are used:

- Grammonite (79 % ammonium nitrate and 21 % TNT) - 35-40 % from total amount of used explosives
- ANFO (94 % ammonium nitrate and 6 % fuel oil) - up to 35 % from total amount
- Ammonite (in wet blastholes and in primers) - up to 30 % from total amount

The diameter of blastholes is 215 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 delay connectors is used with detonating cord and primer in blastholes. In 1996, the experiments with nonelectric systems (Dynashock) were started in *Narva* and *Aidu* open pits.

Table 1. **Blast Vibration Media in *Aidu* Oil Shale Open Pit**

Rock	Thickness, m	Density, Mg/m^3	Compressive strength, MPa	Modulus of elasticity, MPa	Seismic wave propagation velocity, m/s
Sand, moraine	4	1.6–1.9	–	–	1000–1500
Limestone, dolomite	12–13	2.5–2.7	40–70	36000–52000	1600–2500
Oil shale	2.8–3.0	1.3–1.8	20–30	900–1300	700–1300

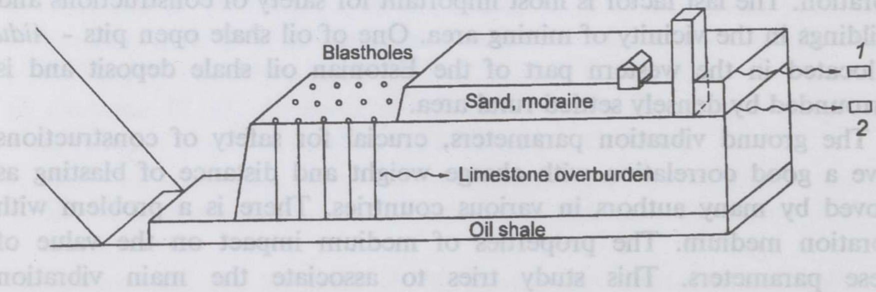

Fig. 1. Ground vibration measurements of overburden blast in *Aidu* open pit: *1* - geophone on the soil; *2* - geophone on the overburden

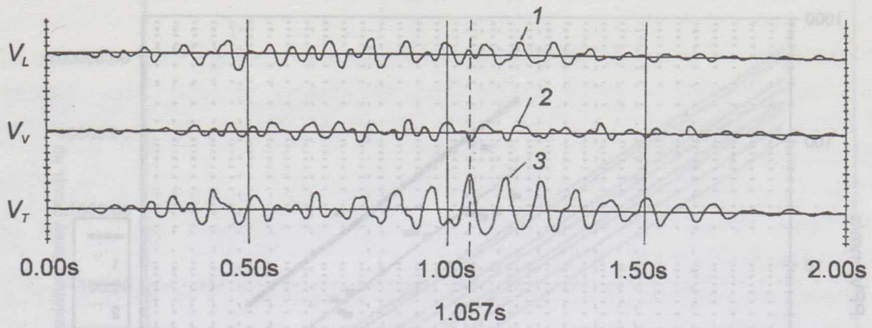

Fig. 2. Typical blast vibration time history record in oil shale surface mining: *1* - longitudinal velocity; *2* - vertical velocity; *3* - transversal velocity

Table 2. **The Ground Vibration Measurements in *Aidu* Open Pit**

Time of blasting	Measuring distance *d*, m	Maximum delay group *Q*, kg/delay	Peak particle velocity *V*, mm/s				Scaled distance d_s	Location of geophone (see Fig. 1)
			Trans-versal	Verti-cal	Longitu-dinal	Vector sum		
29.10.93	1400	1568	1.65	0.76	2.03	2.11	35.35	1
02.11.93	600	1568	8.00	16.89	8.76	17.83	15.15	1
03.11.93	450	2576	17.53	9.40	23.62	23.94	8.87	1
05.11.93	550	2576	5.21	9.02	8.38	9.72	10.83	2
08.11.93	2400	2576	0.38	0.25	0.51	0.56	47.29	1
09.11.93	450	1568	7.24	8.87	5.08	9.86	11.36	1
12.11.93	400	2464	19.81	13.59	22.26	26.56	8.06	1
21.04.94	1750	1856	1.27	0.51	1.90	1.97	40.62	1
23.05.94	2000	1984	0.76	0.38	0.64	0.81	44.90	1
20.06.94	800	990	4.70	2.41	3.94	5.08	25.42	1
28.06.94	250	1824	24.38	24.77	39.75	39.91	5.85	2
30.06.94	550	3168	4.32	13.08	8.00	13.18	8.77	2
04.07.94	600	1664	2,67	3.18	6.22	6.87	14.72	2
05.07.94	350	2464	27.05	13.08	33.15	35.40	7.05	1
12.07.94	275	2468	9.78	11.94	25.15	27.43	5.54	2
20.02.96	1400	1950	1.52	1.65	1.65	2.16	34.10	1
21.02.96	550	290	4.06	4.70	4.83	5.86	32.40	1
23.02.96	550	1740	16.00	5.84	7.87	16.72	13.20	1
27.02.96	550	1450	15.24	16.51	12.19	18.19	14.24	1
04.03.96	550	280	–	–	–	3.81	32.90	1
05.03.96	550	260	3.69	2.16	2.03	4.02	34.20	1
20.05.96	450	1036	16.13	19.30	26.54	28.78	13.98	1
20.05.96	450	1036	4.40	9.89	3.94	10.00	13.98	2
10.06.96	850	1346	19.56	19.18	24.00	25.27	23.16	1
10.06.96	850	1346	5.39	5.80	3.60	6.91	23.16	2
12.06.96	350	1592	61.98	24.38	76.71	87.26	8.77	1
12.06.96	350	1592	25.50	14.50	25.50	34.00	8.77	2
13.06.96	350	1295	19.30	13.84	27.76	25.97	9.72	1
13.06.96	350	1295	5.04	9.70	6.24	12.20	9.72	2
14.06.96	550	1036	4.50	5.70	5.29	7.12	17.08	2

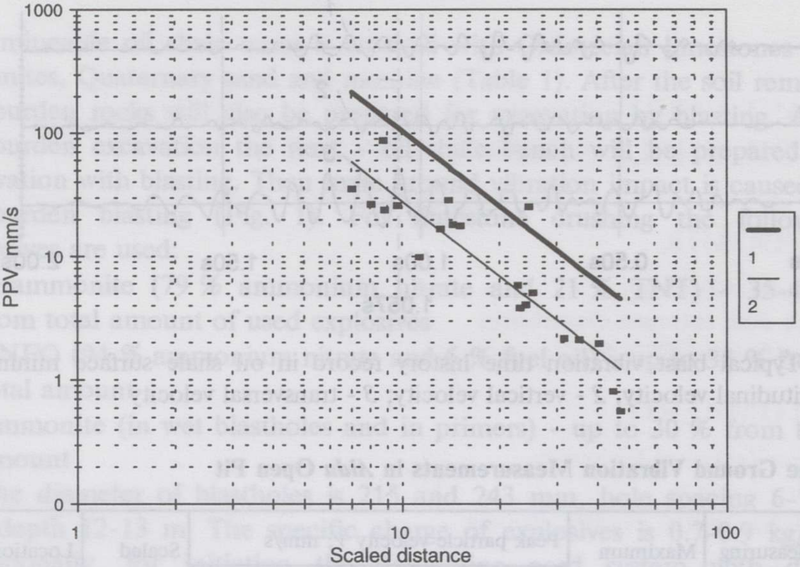

Fig. 3. Variation of peak particle velocities in soil of Quaternary sand and moraine: *1* - 95 % confidence line; *2*- regression equation line

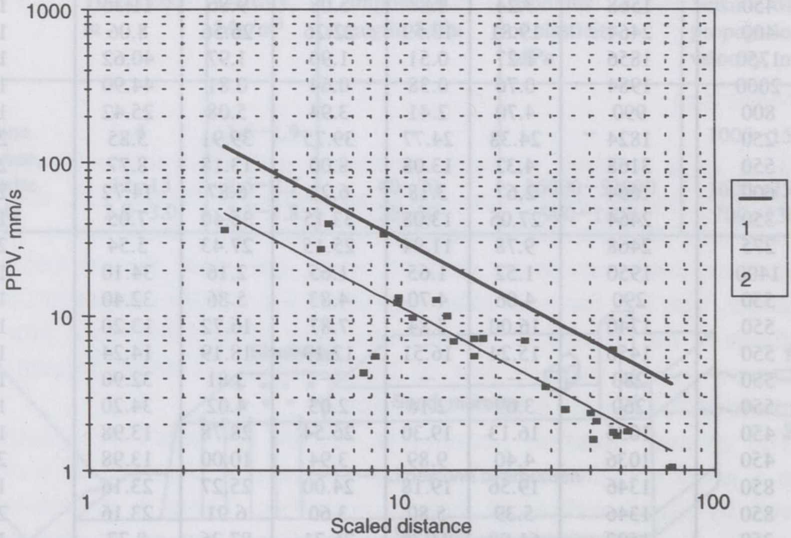

Fig. 4. Variation of peak particle velocities on limestone overburden: *1* - 95 % confidence line; *2*- regression equation line

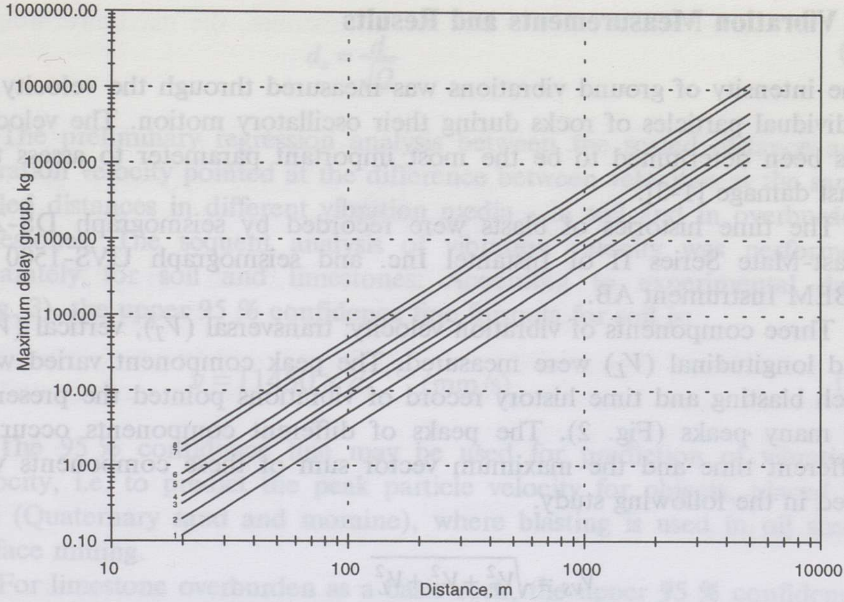

Fig. 5. Charge weight limiting nomograph for Quaternary sand and moraine: *1-8* - for conceded velocities 3, 5, 8, 10, 15, 20, 40, and 50 mm/s, respectively

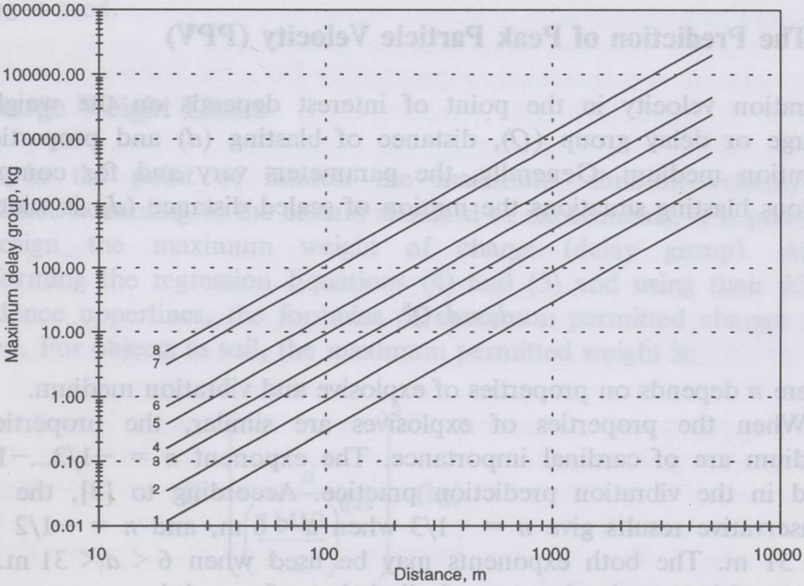

Fig. 6. Charge weight limiting nomograph for limestone overburden: *1-8* - for conceded velocities 3, 5, 8, 10, 15, 20, 40, and 50 mm/s, respectively

2. Vibration Measurements and Results

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 [1-3].

The time histories of blasts were recorded by seismograph DS-277 Blast-Mate Series II of Instantel Inc. and seismograph UVS-1500 of ABEM Instrument AB.

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 (Fig. 2). The peaks of different components occur at different time and the maximum vector sum of these components was used in the following study.

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

For example, in the case of Fig. 2 the maximum occurs in 1.057 s and $V_{VS} = 16.0^2 + 5.0^2 + 0.0^2 = 16.7$ mm/s. The vibration measurements in *Aidu* open pit were carried out for soil and overburden limestones in 1993-1996 (Table 2).

3. The Prediction of Peak Particle Velocity (PPV)

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 various blasting situations the motion of scaled distance (d_s) is widely in use

$$d_s = d \cdot Q^n \qquad (2)$$

where n depends on properties of explosive and vibration medium.

When the properties of explosives are similar, the properties of medium are of cardinal importance. The exponent $n = -1/3 \ldots -1/2$ is used in the vibration prediction practice. According to [3], the more conservative results give $n = -1/3$ when $d < 6$ m, and $n = -1/2$ when $d > 31$ m. The both exponents may be used when $6 < d < 31$ m. The points of interest in the case of oil shale surface 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.

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

The preliminary regression analysis between the scaled distance and vibration velocity pointed at the difference between velocities at the same scaled distances in different vibration media - in soil and in overburden limestones. The sequent analysis of vibration velocity was performed separately for soil and limestones. According to experimental data (Fig. 3), the upper 95 % confidence line formula for soil is:

$$v = 11450 \times d_s^{-2.03} \text{ (mm/s)} \tag{4}$$

The 95 % confidence line may be used for prediction of vibration velocity, i.e. to predict the peak particle velocity for objects, placed in soil (Quaternary sand and moraine), where blasting is used in oil shale surface mining.

For limestone overburden as a basic rock, the upper 95 % confidence line formula is, according to experimental data (Fig. 4):

$$v = 374 \times d_s^{-1.08} \text{ (mm/s)} \tag{5}$$

The 95 % confidence line may be used for prediction the vibration velocity in basic rocks when overburden blasting in oil shale surface mining is used.

4. Charge Weight Limits

When in the point of interest the maximum vibration velocity is established according to the certain standard or experiments, it is possible to design the maximum weight of charge (delay group). After transforming the regression Equations (4) and (5) and using their 95 % confidence upperlines, the formulas of maximum permitted charges are derived. For objects in soil, the maximum permitted weight is:

$$Q = \left(\frac{d}{\left(\frac{11450}{v_{conc}} \right)^{0.49}} \right)^2 \text{ (kg)} \tag{6}$$

where v_{conc} is the conceded vibration velocity.

For objects, situating on overburden limestones, the maximum weight is:

$$Q = \left(\frac{d}{\left(\frac{374}{v_{conc}} \right)^{0.93}} \right)^2 \text{ (kg)} \qquad (7)$$

According to Equations (6) and (7), the nomographs are elaborated to determine the charge weights for various distances and permitted vibration velocities (Figures 5 and 6).

Conclusions

A good correlation between the data of the measured ground vibration velocity and the scaled distance enables to predict the vibration velocity in the rocks of oil shale surface mining area (and in analogous geological conditions). The seismic safety blast design is possible using the elaborated regression formulas and nomographs.

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