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BLAST VIBRATIONS IN OIL SHALE UNDERGROUND MINING

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The blasting is the predominating method of braking mineable rocks in oil shale mines. Regardless of fewer weights of charges than in opencast mining due to shallow location of mineable seam, the distance to possible endangered objects is short. The vibrations were studied in the soil of Quaternary sediments and in Ordovician limestone in the level of underground blasting. The measurements were performed by seismographs DS-277 Blast-Mate Series II of Instantel Inc. and UVS-1500 of ABEM Instruments AB.

The results pointed more intensive vibration decay in vertical direction, transversely to overburden strata than in horizontal direction. The formulas for prediction of vibration velocity and for maximum permitted charge weights were elaborated for basic rocks (limestone) and for soil, for minimum and maximum blasting depths.

Introduction

The hardness of mineable oil shale seam due to limestone intercalations is the reason, that the blasting in mines is still the prevalent method of rock destruction. The blasting is used in working faces of all development headings. The rock blasting is also used in room-and-pillar mining, the predominating mining method in oil shale mines.

The charges of explosives (delay groups) are less in mines than in opencasts, but due to small depth of mines, 20-50 metres from ground surface, the distance to various objects on ground surface may be very short. Therefore blast vibrations impact on surface objects - houses, powerlines and underground objects - wells, pipelines, mine openings themselves will stay actual.

Blasting Conditions

In oil shale mines the blasting is used for breaking the mineable oil shale seam for following loading and transport of mined rock.

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 and 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. 1). In mines the ammonite has a general use. The detonation temperature of this explosive is 2230 °C, energy 3400 kJ/kg and detonation velocity 3.6-4.3 km/s.

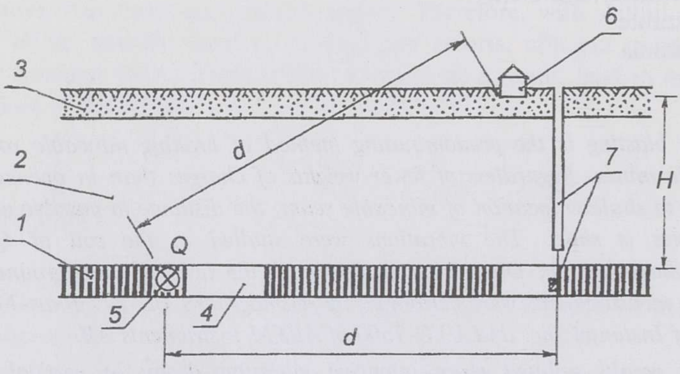

Fig. 1. Vibration measurements of underground blasting: *1* - mineable seam, *2* - limestone overburden, *3* - soil, *4* - mine working, *5* - charge *Q*, *6* - geophone in soil, *7* - geophone in basic rocks

The shot method is in use, every shot has usually a charge 0.6-0.9 kg ammonite in cartridges with average specific consumption of explosive 0.7-0.8 kg/m^3. By using the short-delay blasting the weight of delay groups vary among 2-36 kg. Short-delay blasting caps have the delays from 0 to 500 milliseconds. The total weight of delay group depends on the number of simultaneously blasted faces.

Vibration Measurements and Results

In this study the vibration velocity of individual particles of rocks due to blast impulse was taken for the main parameter [1-3] as in the previous study for surface mining [4]. The seismograph DS-277 Blast-Mate

Series II of Instantel Inc. and seismograph UVS-1500 of ABEM Instrument AB were used to record the time histories.

The typical underground blast time history with six delay groups recorded on ground surface is shown on Fig. 2. The maximum sum of three components occurred on 55 mm/s. Three components of vibration velocity, transversal, vertical, longitudinal and vector sum of these components were measured. In the following study the vector sum as a maximum possible velocity was used.

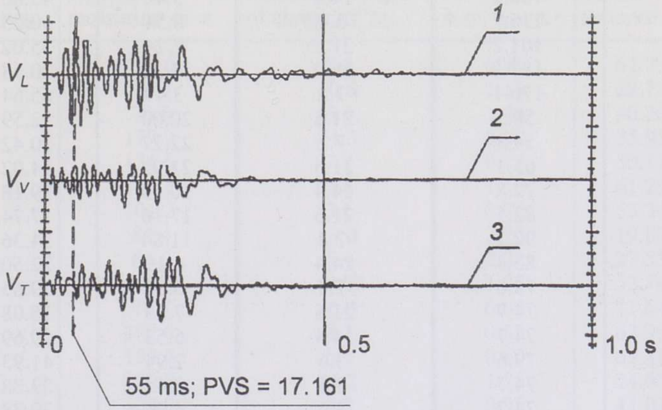

Fig. 2. Vibration velocity time history record in mine blasting: *1* - longitudinal, *2* - vertical, *3* - transversal

Table 1. **Vibrations in Basic Rocks-Limestone, *H* = 0 m**

No of blasting	Distance of measuring *d*, m	Maximum weight of charge *Q*, kg	PPV, vector sum, mm/s	Scaled distance d_s
1	200	14.4	1.78	52.70
2	190	21.6	1.58	40.88
3	180	14.4	1.76	47.43
4	60	10.8	7.14	18.26
5	190	22.5	2.35	40.06
6	185	14.4	1.67	48.75
7	110	5.4	6.02	47.34
8	195	21.6	2.07	41.96
9	200	36	2.48	33.33
10	195	7.2	1.05	72.67
11	60	21.6	12.70	12.91
12	155	16.20	2.58	38.51
13	45	10.80	19.90	13.69
14	155	24.30	2.56	31.44
15	110	7.20	7.47	40.99
16	90	3.60	8.51	47.43
17	75	3.60	7.89	39.53
18	55	18.00	21.10	12.96
19	20	5.40	39.30	8.61
20	75	9.00	8.59	25.00
21	30	36.90	44.20	4.94

Table 2. **Vibrations in Soil on Ground Surface, the Depth $H = 20$ m**

No of blasting	Distance of measuring d, m	Maximum weight of charge Q, kg	PPV vector sum, mm/s	Scaled distance d_s
1	171.2	14.4	6.54	45.11
2	171.2	21.6	5.51	36.83
3	171.2	14.4	4.24	45.11
4	53.9	10.8	10.81	16.39
5	161.2	22.5	3.22	33.99
6	171.2	14.4	2.70	45.11
7	166.2	14.4	3.44	43.80
8	116.7	5.4	8.54	50.23
9	161.2	21.2	7.24	35.02
10	181.1	36.0	11.22	30.18
11	176.1	7.2	3.49	65.64
12	58.5	21.6	20.00	12.59
13	54.8	7.2	22.27	20.42
14	65.1	21.6	21.92	14.02
15	72.8	14.4	10.59	19.18
16	82.5	21.6	17.16	17.74
17	92.2	7.2	11.84	34.36
18	85.4	14.4	4.19	22.50
19	79.6	7.2	6.57	29.65
20	74.7	21.6	7.83	16.08
21	74.7	14.4	6.53	19.69
22	79.6	3.6	2.94	41.93
23	74.7	3.6	3.45	39.38
24	74.7	3.6	4.06	39.38
25	74.7	7.2	6.83	27.85
26	85.4	7.2	8.22	31.82
27	77.6	7.2	6.42	28.93
28	102.0	3.6	3.83	53.75
29	124.6	7.2	6.19	46.44
30	72.8	7.2	7.02	27.13
31	52.0	7.2	37.31	19.38
32	44.7	3.6	29.07	23.57
33	79.6	3.6	18.40	41.93

For comparison the results of various blasting conditions, the charge weights Q and the distances d of measurements the notion of scaled distance was used.

$$d_s = d \cdot Q^n \qquad (1)$$

The exponent $n = -0{,}5$ if $d > 6$ m [3].

According to vibrations measurement schema various Q, d and H (see Fig. 1) were used. Preliminary study of peak particle velocity (PPV) function on scaled distance on log/log field showed that the deviation of data from straight line on short horizontal distances d, i.e. the influence of the thickness of horizontally laying sedimental rocks remarkably impacts on the attenuation of vibration.

This matter caused to group the data according to levels between the locations of charge and objects of interest. Three cases were chosen:

1. Blasting in oil-shale seam, measuring in basic rocks-limestone at the same level, $H = 0$ m (Table 1)

2. Blasting in oil-shale seam, measuring in soil (ground surface), $H = 20$ m; i.e. minimum depth of underground mining (Table 2)
3. Blasting in oil-shale seam, measuring in soil, H = 50 m; i.e. the depth of most cases of underground mining (Table 3). The maximum depth of blasting is over 60 m

Table 3. **Vibrations in Soil on Ground Surface, the Depth $H = 50$ m**

No of blasting	Distance of measuring d, m	Maximum weight of charge Q, kg	PPV vector sum, mm/s	Scaled distance d_s
1	191.6	9.6	0.99	61.85
2	94.3	10.8	1.56	28.71
3	76.6	3.6	1.44	40.36
4	177.2	24.3	0.68	35.95
5	134.6	7.2	0.73	50.17
6	116.3	3.6	1.19	61.29
7	101.2	3.6	0.70	53.34
8	84.4	18.0	2.70	19.89
9	64.0	5.4	2.22	27.55
10	101.2	9.0	1.87	33.74
11	70.7	36.9	6.03	11.64
12	182.0	8.1	0.52	63.95
13	153.4	6.3	0.50	61.11
14	120.8	25.2	1.25	24.07
15	103.0	6.3	0.95	41.02
16	82.0	6.3	0.94	32.67
17	53.9	9.0	8.11	17.95
18	61.0	9.0	5.22	20.34
19	70.7	9.0	3.27	23.57
20	82.0	9.0	1.51	27.34
21	156.2	5.4	0.65	67.23
22	170.5	5.4	0.75	73.37
23	178.2	5.4	0.81	76.67
24	54.6	5.4	4.57	23.51
25	72.9	5.4	2.52	31.36
26	82.0	5.4	2.41	35.29
27	144.0	5.4	0.98	61.95
28	156.2	5.4	0.98	67.23
29	170.5	5.4	0.60	73.37
30	183.9	5.4	0.97	79.15

The Peak Particle Velocity of Blast Vibration

The statistical analysis of data for the first case, when the vibration was measured in limestone, show the good correlation between PPV and scaled distance with factor - 0.86 (Fig. 3*a*). The regression equation for this case is:

$$V = 560 \cdot d_s^{-1.393} \text{ (mm/s)} \qquad (2)$$

where V is peak particle velocity;
d_s is scaled distance.

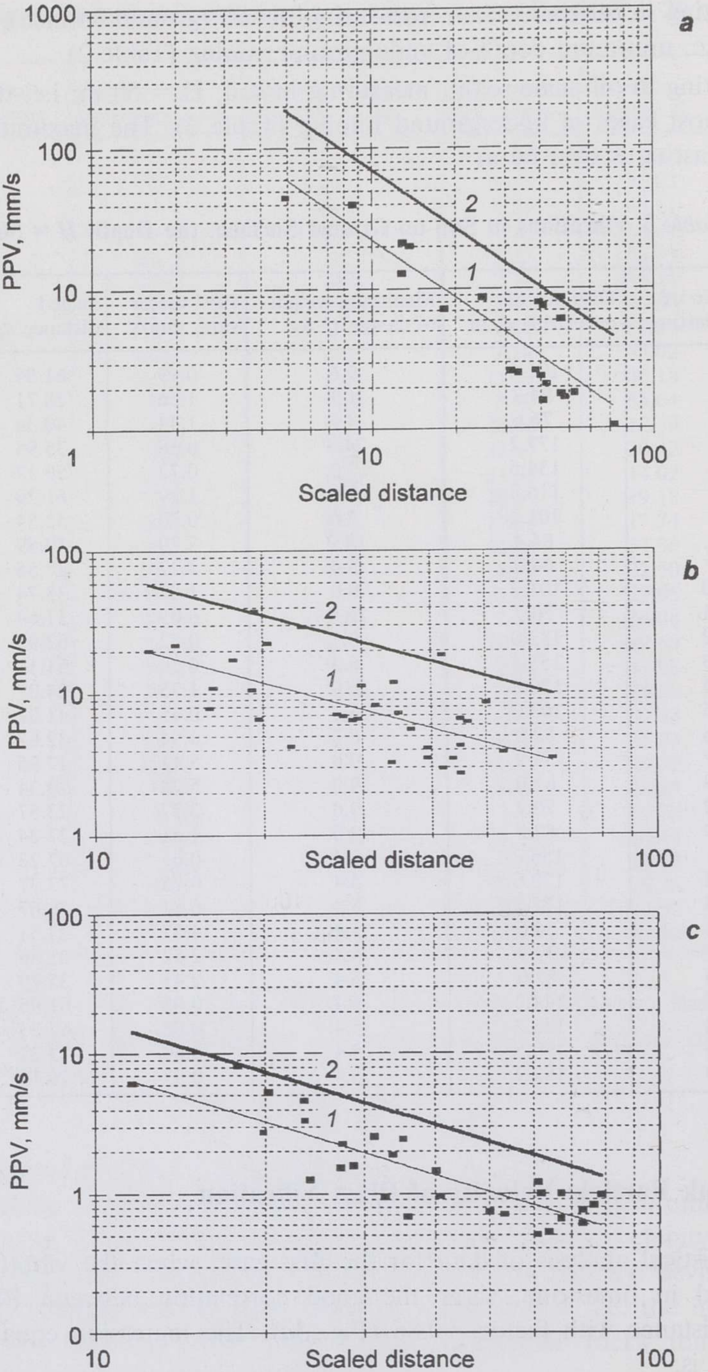

Fig. 3. Variation of peak particle velocities: *a* - in basic rocks (limestone), blasting level $H = 0$; *b* and *c* - in soil, blasting depth (*b*) $H = 20$ m and (*c*) $H = 50$ m. *1* - regression equation line, *2* - 95 % confidence upper line

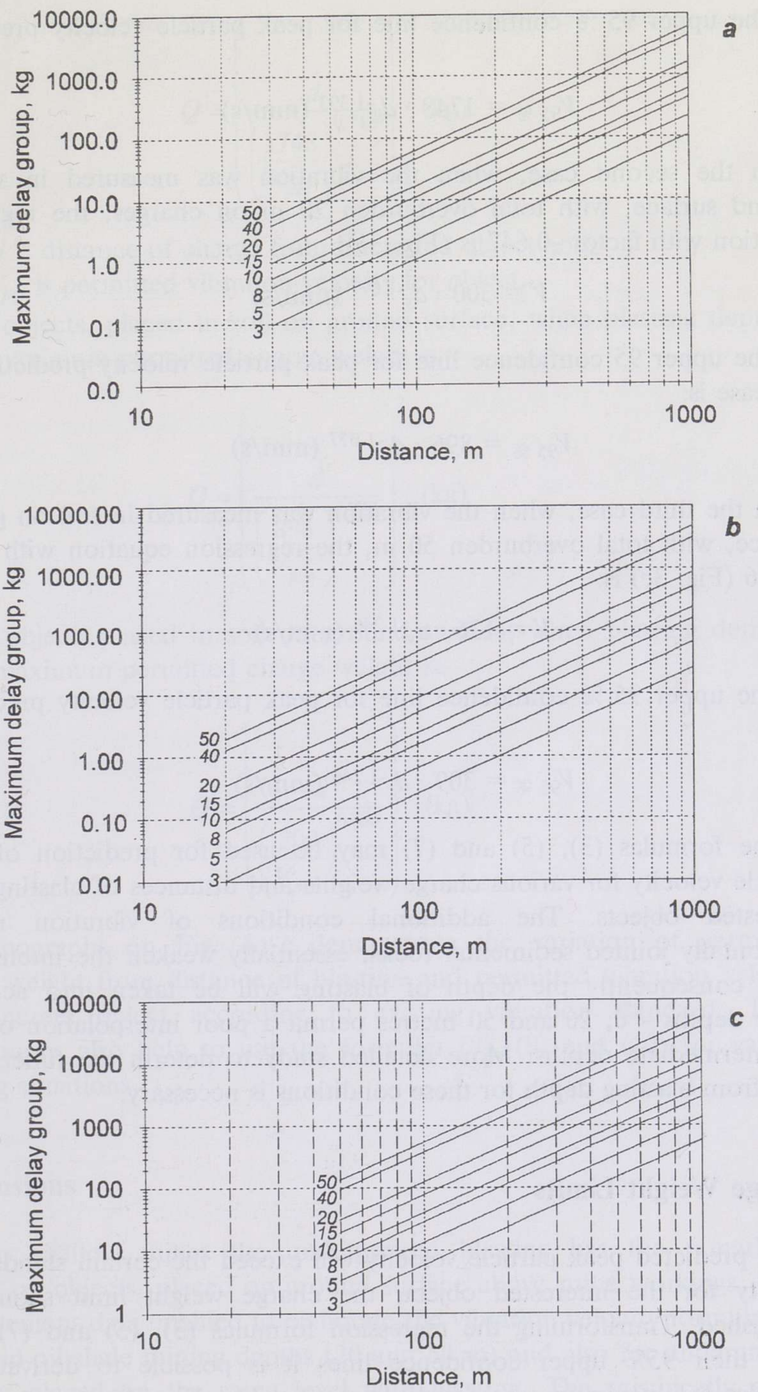

Fig. 4. Charge weight limiting nomograph: *a* - for basic rocks (limestone), blasting level $H = 0$; *b* and *c* - for soil, blasting depth (*b*) $H = 20$ m and (*c*) $H = 50$ m. Given (permitted) velocities are 3, 5, 8, 10, 15, 20, 40 and 50 mm/s

The upper 95 % confidence line for peak particle velocity prediction is:

$$V_{95\ \%} = 1748 \cdot d_s^{-1.393}\ \text{(mm/s)} \qquad (3)$$

In the second case, when the vibration was measured in soil on ground surface, with total overburden 20 m on charges, the regression equation with factor -0.647 is (Fig. 3*b*):

$$V = 300 \cdot d_s^{-1.077}\ \text{(mm/s)} \qquad (4)$$

The upper 95 confidence line for peak particle velocity prediction for this case is:

$$V_{95\ \%} = 896 \cdot d_s^{-1.077}\ \text{(mm/s)} \qquad (5)$$

In the third case, when the vibration was measured in soil on ground surface, with total overburden 50 m, the regression equation with factor -0.846 (Fig. 3*c*) is:

$$V = 136 \cdot d_s^{-1.246}\ \text{(mm/s)} \qquad (6)$$

The upper 95 % confidence line for peak particle velocity prediction is:

$$V_{95\ \%} = 309 \cdot d_s^{-1.246}\ \text{(mm/s)} \qquad (7)$$

The formulas (3), (5) and (7) 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 sedimental rocks, essentially weaken the intensity of PPV, consequently the depth of blasting will be taken into account. Three depths - 0, 20 and 50 metres permit a poor interpolation of data for intermediate depths. More detailed study to determ the function of PPV from blasting depth for these conditions is necessary.

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. Transforming the regression formulas (3), (5) and (7), and using their 95% upper confidence lines it is possible to derivate the formulas for maximum permitted charge weights. For objects, placed in basic rocks, in limestone at the same level of blasting, the maximum permitted charge weight is:

$$Q = \left(\frac{d}{\left(\frac{1748}{V_{per}} \right)^{0.718}} \right)^2 \text{ (kg)} \tag{8}$$

where d is distance of charge from interested object and;

V_{per} is permitted vibration velocity for object.

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

$$Q = \left(\frac{d}{\left(\frac{896}{V_{per}} \right)^{0.929}} \right)^2 \text{ (kg)} \tag{9}$$

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

$$Q = \left(\frac{d}{\left(\frac{309}{V_{per}} \right)^{0.803}} \right)^2 \text{ (kg)} \tag{10}$$

Nomographs on Fig. 4*a-c* demonstrate the variation of permitted charge weight from distance of blasting and permitted vibration velocity for concrete object according to existing vibration standard. These nomographs also help to use the formulas (8), (9) and (10) for various blasting situations.

Conclusions

Due to shallow mines the underground blasting has the remarkable impact on objects, placed on ground surface above mine workings. Field measurement data enabled to elaborate the vibration velocity formulas for extremal oil shale mining depths (20 and 50 m) and also for underground objects, placed on the same level with blasting. The seismically safety charge weights may be designed for these conditions.

The data analyse also pointed vary 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.

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