Survey of seismic conditions of drilling and blasting operations near overhead electricity power lines

G I Korshunov, P I Afanasev, I A Bulbasheva
Saint-Petersburg mining university, 2, 21st Line, Vasilevsky Island, St Petersburg 199106, Russia
E-mail: ines-77@yandex.ru

Abstract. The monitoring and survey results of drilling and blasting operations are specified during the development of Afanasyevsky deposit of cement raw materials for a 110 kV electricity power lines structure. Seismic explosion waves and air shock waves were registered in the course of monitoring. The dependency of peak particle velocities on the scaled distance and explosive weight by the delay time was obtained.

1. Introduction
The development of the Afanasyevsky deposit of cement raw materials, which is done by the explosive method, is complicated by the availability of secure facilities located near the deposit, among which there are 110 kV overhead electricity power lines. These electricity power lines transmit electrical power within the districts of Moscow region, as well as for some important enterprises. The mutual arrangement of electricity power lines and blocks in the plan view is shown in figure 1.

Figure 1. Layout of quarry, EPL, blocks, seismic recording points

A 110kV overhead line is a system of power equipment, each link of which consists of two dead-end towers and five reinforced concrete span poles [9]. Span poles 24 m high are the most vulnerable links of the electricity power lines structure, because they do not have bases, but are simply buried into
soil at the depth of 3.3 meters.

The explosion load monitoring is done for the purpose of intensity detection of seismic explosion and air-shock wave impact of drilling and blasting operations on electricity power lines.

2. Materials and methods

The registration of seismic vibrations was done in three points: point №1 on the quarry side (the scaled distance from the block to the seismographic point was 150-175 m), point №2 on the quarry side (the scaled distance from the block to the seismographic point was 300-350 m), point №3 on the electricity power lines structure (the scaled distance from the block to the seismographic point was 750 m) (figure1).

Mobile seismographic systems were installed in seismographic points as follows: 2 MinimatePro4 seismographic systems, which are a four-channel meter model (four record channels for one three-axis geophone (ISEE or DIN) and linear ISEE microphone) and a ZET 048-C seismographic system, being a three-component seismic sensor. MinimatePro4 sensors were installed at the quarry sides of an overburden bench; the overburden bench with a total depth of 30 meters consists of clay loams, fen clay, moraine clay, Jurassic clay.

The ZET 048-C seismic sensor was fixed directly at a reinforced concrete electricity power lines pole via a rigid steel bracket.

2.1. Experimental large-scale explosions.

A large-scale explosion was done in the marl block on the horizon of +128.6 to +128.7. The block was bored by 14 boreholes of the 8.5 m depth with the diameter of 133 mm. The borehole pattern is 5.5 x 5.5 m (the main parameters are specified in table 1). The rock hardness is 3-6 by the scale of prof. M.M. Protodyakonov. The maximum explosive weight in the block was 984 kg. The boreholes were united into 2 groups of 492 kg explosive weight. The groups were initiated row by row with a delay of 67 ms between rows. The granulite, igdanite explosive (ammonia nitrate with diesel fuel) was used to charge boreholes, and 6ZhV ammonite was used as a primer (the scheme of block charge is specified in figure 2). The maximum weight of simultaneously exploded explosives was 492 kg.

| Parameter name                                      | Value   |
|-----------------------------------------------------|---------|
| Quantity of boreholes, pcs                         | 14      |
| Diameter of boreholes, mm                          | 133     |
| Distance between rows of boreholes / per row, m    | 5.5/5.5 |
| Subdrilling of boreholes, m                        | 1.3     |
| Height of water, m                                  | -       |
| Specific charge of explosive, kg/m³                 | 0.36    |

The large-scale explosion took place on 26.11.2015. An explosion was done at a limestone block on the horizon of +110.1 to +107.1. The block was bored by boreholes of 4 m depth. The quantity was 83 boreholes with the diameter of 133 mm. The borehole pattern is 4 x 4 m (the main parameters are
specified in table 2). The rock hardness is 3-6 by the scale of prof. M.M. Protodyakonov. The main explosive weight in the block was 1780 kg. The boreholes were united into 8 groups; the simultaneously exploded weight was from 60 to 300 kg. The groups were initiated in series with a delay of 42 ms (figure 3). The granulite, igdanite explosive (ammonia nitrate with diesel fuel) was used to charge boreholes, and 6ZhV ammonite was patronized. The maximum weight of simultaneously exploded explosive was 300 kg.

The layout of boreholes is represented in the firing circuit scheme.

![Figure 3. Layout of boreholes in firing circuit scheme. Large-scale explosion of 26.11.2015](image)

Table 2. Main parameters of large-scale block explosion.

| Parameter name                                    | Value |
|---------------------------------------------------|-------|
| Quantity of boreholes, pcs                        | 83    |
| Diameter of boreholes, mm                         | 133   |
| Distance between rows of boreholes / per row, m   | 4/4   |
| Subdrilling of boreholes, m                        | 1.0   |
| Height of water, m                                 | -     |
| Specific charge of explosive, kg/m³                | 0.43  |

3. Results. Description of seismic explosion waves.

One more large-scale explosion was arranged on 25.11.2015. The intensity of seismic impact of drilling and blasting operations was determined by the maximum vibration velocity.

Figure 4 specifies explosion seismograms, registered by the MinimatePro4 seismographic system at the quarry side. The red registrogram is the velocity of vertical vibrations, the blue one is the radial component of lateral vibrations towards the direction perpendicular to the electricity power lines; the green as the tangential component and velocity of lateral vibrations was directed in parallel with the electricity power line itself (figure 1). The forth registrogram from the top is the velocity of air-shock wave; the fifth one is the vector velocity of soil vibrations. The time in seconds is depicted at the axis of abscissa; the velocity of vibrations in mm/s is depicted along the axis of ordinates.
Figure 4. Seismographic record of seismic vibrations of explosion, dated November 25, 2015. Recording place: seismographic point 1 at the quarry side at distances of 175 m, 350 m. Top down: vertical component, tangential component, radial component, registrogram of air-shock wave, vectorial velocity.

The duration of block vibrations after an explosion at the distance from the block of 175m is about 0.6 seconds (figure 4а). However, the visible period of vibrations is about 0.08 s. The seismogram consists of two wavetrains, which correspond to two delay times during explosive detonation. The radial component is divided into two parts because, after the air-blast arrival during the initiation of the first row of boreholes, the seismogram depicts a fadeout, because the delay between boreholes is 68 ms. The maximum velocity of vibrations from the first-time explosive detonation was 18.73 mm/s. The fadeout block vibrations from the first wavetrain arrival were intensified by the second wavetrain arrival, and the maximum velocity of block vibrations reached 23.94 mm/s. The values of 12-14 Hz were the specific frequencies of soil vibrations.

Figure 4b shows registered seismograms of vibration velocities on the horizon of +148.1 at a distance of 350m from the block. The seismogram analysis shows that the duration of block vibrations is about 0.9s that is 0.3s higher than the one, registered by the first sensor (seismographic point 1, figure 4а), and is defined by the phase difference of longitudinal and transversal wave which is proportional to the value of the scaled distance.

The maximum velocity of vibrations is 7.5 mm/s. In the first case, such value is reached by overlapping wavetrains from delay times and intensification of block vibrations, that is clearly visible in the vectorial velocity seismogram as well as in all three components. The values of 12-14 Hz were the specific frequencies of soil vibrations.

Let us consider the large-scale explosion arranged on 26.11.2015. The registration of a seismic explosion wave during the explosion of 26.11.2015 was done at the quarry side, on the horizon of +148.1 at a distance of 150-300m from the block. The duration of block vibrations after the explosion is about 1.27 seconds (figure 5а). The seismogram has a complicated configuration. The seismogram shows that it is difficult to relate separate wavetrains with the initiation of separate rows of boreholes. The time interval between delay times was 42 ms, so the wavetrains from explosion of all the delays were formed.
Figure 5. Seismographic record of seismic vibrations of explosion dated November 26, 2015. Recording place: seismographic point 2 at the quarry side at distances of 150 m, 300 m. Top down: vertical component, tangential component, radial component, registrogram of air-shock wave, vectorial velocity.

The seismogram can be conditionally divided into 2 portions (figure 5a). In the first portion, the duration of vibrations is 0.23 ms, and it is characterized with comparatively small vibration amplitudes (the maximum amplitude in the vertical component reaches 3.3 mm/s), as well as with the period of 0.012-0.015 ms; vibrations at this portion describe the passage of seismic explosion wave on the block. The second seismogram portion is characterized with a surge of amplitude, which is clearly visible from the seismogram of the vertical component of vibrations (the velocity reaches 4.7 mm/s), including the augmentation of the vibration period. The vibration period by three components varies within 43-56 ms; the vibration period by the vectorial velocity is equal to about 30 ms. Such character of vibrations corresponds to the block swing even after the passage of a seismic explosion wave [8]. That is why the maximum vibration velocities both by components and by the total component is the block reaction after the passage of a seismic explosion wave. The maximum vibration velocity by the vectorial velocity is 10 mm/s.

The analysis of a seismogram, registered at a distance of 300 m from the block (figure 5b) shows that the duration of block vibrations is about 1 s. The maximum vibration velocity is 6.06 mm/s and, as, in the first case, it is reached by swinging of the overburden block, at which surface the seismic sensors were installed. The values of 8, 10-15 Hz were the specific frequencies of soil vibration.

The pattern of vibrations is specific for overburden formations represented by loamy sands, clays and loess-like loams, having a small hardness coefficient by the scale of prof. M.M. Protodyakonov (0.6-1.5). This type of overburden formations is a filter, passing low frequencies. That is why the frequency spectrum varied from 8 to 15 Hz [7].

Air-shock waves from explosions were recorded in two seismographic points 1 and 2 (figure 1), located at the quarry sides. The difference of elevations at the level of the block and the side to be blasted, where the waves were recorded, was about 40 meters that contributed to the intensity reduction of an air-shock wave. Figures 4, 5 showed air wave registrograms. As the distances were small (to 400 m), then it is clearly visible in the figure that the wave is a superposition of explosion waves from separate delay times. Depending on seismic explosion waves, the acoustic explosion
effect shall be related to the total explosion yield, but not to the explosive weight within one delay time.

The maximum pressure at the wave peak was 112.5 Pa at the distance of 175 m from the block to be exploded. The air wave registrograms demonstrate that with increasing the distance, the wave intensity decreases, reaching the value of 35.7 Pa at a distance of 350 m.

The impact on the building glazing, withstanding the overpressure of 500 Pa, is used as the air-shock wave intensity criterion. The values obtained during monitoring are equal to 112.5 Pa, that is 4 times lower than the allowable overpressure. [4,6]

**Vibrations registered at the electricity power lines pole.** An accelerogram record was obtained at the electricity power lines pole. After the accelerogram integration, the velocities of vibrations by components, as well as the vectorial velocity and pole movements, were obtained (figure 6).

![Figure 6](image)

**Figure 6.** Seismograms of seismic vibrations from explosion dated November 25, 2015 (figure 6a) and November 26, 2015 (figure 6b). Registration place: seismographic point 3 at electricity power line pole. Sig_1_1 – velocity in the x axis (axis was directed along electricity power lines); Sig_1_2 – velocity in the y axis (axis was directed perpendicular to the electricity power lines); Sig_1_3 – velocity in the z axis (vertical direction). Fourth seismogram from the top – vectorial velocity (mm/s); fifth seismogram – particles displacement (mm).

The sensor was fixed on the structure so that the axis OX (Sig_1_1) was oriented to the electricity power line axis, thus the maximum velocity of vibrations was recorded as 0.76 mm/s. The axis OY (Sig_1_2) was oriented orthogonally to the electricity power line at the shortest distance to the block; the maximum velocity of pole vibrations was 0.77 mm/s (figure 1). The velocity along the axis OZ was 0.59 mm/s. The total time of explosion vibrations was 3.8 s. The maximum vectorial velocity was 0.95 mm/s, and the displacement was 0.05 mm.

The vibrations, corresponding to the explosion time, are characterized with a small amplitude and period of 0.1 s. Explosion vibrations lasted during 1 s, then the pole continues oscillative motions with the growing amplitude, reaching the maximum velocities; the time of free pole vibrations after the passage of a seismic explosion wave for 2.2 s.

During the spectral seismogram factorization, it emerged that the specific frequency of pole vibrations was 4 Hz and 12 Hz. The total frequency spectrum does not exceed 25 Hz. During the seismogram implementation into the Fourier series, the weight window function with a flat top of 1 Hz frequency resolution and 0.01 s averaging time was used.
Figure 6b shows velocitograms of electricity power line pole vibrations from the explosion of November 26, 2015. As a result of the velocitogram analysis, it should be noted that the main vibrations caused by the explosion lasted during up to 2 seconds. Then the exhaustive process occurs, which lasts during 6 seconds. This circumstance is caused by that the second mass explosion consisted of 8 rows of boreholes (mass explosion of 25.11.2015 consisted of 2 rows of boreholes), which caused the occurrence of pole self-vibrations.

The maximum velocity of vibrations up to the axis $O_X$ ($\text{Sig}_1\_1$) was 0.96 mm/s; the maximum velocity of pole vibrations along the axis $O_Y$ ($\text{Sig}_1\_2$) was 1.0 mm/s (fig. 1); the velocity along the axis $O_Z$ was -0.48 mm/s. The total time of explosion vibrations was 8 s; the maximum vectorial velocity was 1.14 mm/s, and the displacement was 0.05 mm.

The specific pole vibration frequencies were 10 Hz and 20 Hz. The total frequency spectrum does not exceed 25 Hz.

4. Discussion
Comparison of pole vibrations from two mass explosions. The comparative analysis of electricity power line pole vibrations during two mass explosions showed that the maximum velocity of pole vibrations, having reached the value of 1.14 mm/s, was caused by the second explosion of 26.11.2015 (figure 7). However, if to analyze the values of vibration velocities, recorded at the overburden bench, then from vibration velocitograms, it follows that the second mass explosion caused less intensive soil vibrations. While the seismic recorders during the second mass explosion of 26.11.2015 were located by 50 m closer to the block, the velocities of soil vibrations were 2 times lower than vibration velocities, gained during the mass explosion of 25.11.2015 (Table 3).

| Large-scale explosion parameters | Large-scale explosion of 25.11.2015 | Large-scale explosion of 26.11.2015 |
|----------------------------------|-------------------------------------|-------------------------------------|
| Simultaneously exploded charge weight, kg | 425 | 300 |
| Delay interval between borehole rows, ms | 67 | 42 |
| Quantity of rows, pcs | 2 | 8 |
| Total weight of explosives on block, kg | 984 | 1780 |
| Distance to electricity power lines pole, m | 800 | 700 |
| Distance from block to seismographic point 1, m | 175 | 150 |
| Distance from block to seismographic point 2, m | 350 | 300 |
| Maximum vectoral velocity on electricity power lines, mm/s | 0.95 | 1.17 |
| Maximum vectoral velocity at side in seismographic point 1, mm/s | 24.0 | 10.00 |
| Maximum vectoral velocity at side in seismographic point 2, mm/s | 7.5 | 6.1 |

Therefore, the maximum mass of simultaneously exploded charge of the explosive with a delay influences the value of vibration velocities on a ledge. At the same time, the velocitograms of pole vibrations showed that the maximum vibration velocities on the structure depend on the explosion duration (quantity of borehole rows and delay time between boreholes).

According to the Russian requirements, specified to the construction of reinforced concrete structures in seismic areas, one should be guided by SNiP II-7-81 “Construction in seismic areas” [1]. The design and construction of buildings and structures in a 5-point area [2] are made without the application of special aseismic structures. Designed and constructed electricity power lines as per
SNiPs were designed to withstand and remain undamaged at a 5-point impact with the event probability of 1% for 50 years with the velocity of seismic vibrations of 15 to 30 mm/s (see the magnitude scale of seismic intensity).

Depending on the earthquakes, the explosions at this deposit were made with a higher periodicity, namely 2-3 times per week during the time of deposit development. So, the SNiP does not consider the intensity of explosion impact, because the explosion works approach electricity power lines at a distance of up to 150 m.

5. Conclusions.

So as a result of the conducted monitoring, the following conclusions were made:

1. The maximum vibration velocities, recorded at the overburden bench (on soil), depend on the simultaneously exploded weight of the explosive, taking place per one delay time, as well as at the delay time and scaled distance. The explosion at the marl ledge dated 25.11.2015 led to vibrations of the open-pit block, high by their amplitude, while the scaled distance and delay time were higher than those during the explosion dated 26.11.2015. It is explained by the fact that the highest impact is caused by the weight of the simultaneously exploded explosive per delay time.

2. Overburden rocks, characterized by small strength coefficients, have a response to the explosion as durable vibrations with the growing amplitude, reaching the maximum values after the passage of a seismic explosion wave through soil.

3. The maximum vibration velocities, recorded on the electricity power lines structure, depend on the total explosion duration: the maximum vibration velocities on the electricity power lines structure was caused by the explosion on a mark block dated 26.11.2015, having lower power but higher area (8 rows of boreholes), and, accordingly, higher duration.

4. Air-shock waves during drilling and blasting operations due to the difference of altitudes of 30 m between overburden and production benches have the amplitude, not exceeding 125 Pa, and are not dangerous for the population and protected facilities.

5. Subsequently it is required to make a calculation of frequencies of natural oscillations of the electricity power lines structure for their further comparisons with frequencies of induced oscillations from explosions.

The necessity of more detailed consideration of the electricity power lines structure, shock resistance against the impact of seismic explosion loads is stipulated because according to the regulatory documents of the Russian Federation, the seismic loads are related to the special ones (the earthquake probability is 1%), while the explosions have the 100% probability and more frequent repeatability.

References

[1] SNiP II-7-81 1981 *Construction in seismic regions*. Gosstroy USSR
[2] General seismic zoning of the territory of the Russian Federation OSR-97. Map folio for SNiP II-7-81 «Construction in seismic regions» 1981
[3] Tsetlin Ya and ISmolin N I 1981 *Seismic and shock air waves from industrial blasts* (Moscow: Nedra) p 191
[4] Orelno L P 2004 *Physics of blast* (Moscow:FIZMATLIT) p 832
[5] Medvedev S V 1964 *Seismic of rockburst* (Moscow: Nedra) p 188
[6] Unified safety regulation for explosive operations PB 13-407-01
[7] Kriger N I, Aleshin AS, Kozhevnikov A D, Mindel IG1980 *Seismic characteristics of loess waste in relation to geological surrounding and technogenesis* (Moscow: Nauka) p. 104
[8] Yakobshvili O P 1992 *Seismic methods of estimate of rock massive state in the quarries* (Moscow: IPKON RAN) p 254
[9] Krukov K P and Novgorodtsev B P 1979 *Construction and mechanical design of electricity power lines* (Leningrad: Energiya) p 307
Yurevich G G, Belyakov V D, Sevastianov B N 1972 *Protection of excavated areas from blasting operations influence* (Moscow: Nedra) p 136