Seismic safety of buildings and structures during iron ore mining

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Abstract. The purpose of the work is to control the level of the impact of explosions on buildings and structures in order to ensure the safety of industrial and civil facilities, to accumulate information about the possible impact of tectonic disturbances on the energy and propagation of elastic waves arising during technological explosions. Control of the impact of explosions is carried out using a software and hardware complex created on the basis of geophysical equipment. The complex registers the parameters of the seismic wave, then their digital processing is performed. The article provides brief information about the deposit being developed by the mine and the history of its development. The reasons for updating the repeated studies of the impact of drilling and blasting operations on buildings and structures are described. Experimental results obtained during registration of the seismic effect from technological explosions at the "Magnetitovaya" iron ore mine are presented. The calculated values and their comparison with the current tolerances are given. Conclusions are made about the size of the impact on the objects under study. A measurement technique and subsequent processing of the data obtained are described.

1. Introduction
In the Urals, where a number of deposits have been developed since the beginning of the 18th century, factory-type territories have historically formed, where residential and other socially significant objects are located in close proximity to mining enterprises. Especially from such territories stands out the city of Nizhny Tagil (Russia), where residential areas are intertwined with industrial ones. The object under consideration near the residential area was the Magnetitovaya iron ore mine. Since the extraction of ore is carried out using blasting operations, both underground and on the surface, the question of the seismic safety of industrial and social infrastructure from technological explosions arises.

The Vysokogorskoye iron ore deposit, developed by a combined method, including the Magnetitovaya mine, was mentioned at the end of the 17th century, is the oldest and largest deposit in the Urals. Industrial development began in 1721. In 1725, the Nizhniy Tagil (Russia) iron-smelting and iron-making plant was built, where the largest blast furnace in Europe at that time was launched in the same year [1].

The mineral mined at the deposit - magnetite - a natural iron oxide [2], did not contain harmful impurities and therefore the metal smelted from it was of high quality, also, the admixture of manganese and copper improved the properties of the metal - they were natural alloying components.

Until 1918, the deposit was mostly developed by open pit mining. Mine "Magnetitovaya" began work in 1944. The industrial site of the mine houses industrial infrastructure facilities: administrative and amenity plants, hoisting machines, a compressor room, and a mine fan. For each of the above
objects, there are federal permissible displacement rates and amplitudes of these displacements
determined by the federal authorities. Determination of the displacement rates and the amplitude of these
displacements has been carried out since the 60s of the 20th century.

As you know, the extraction of ore is carried out using drilling and blasting technology through the
production of regular technological and massive explosions both underground and in the sides of the
quarry, that is, on the surface. For facilities subject to protection from the harmful seismic effects of
explosions, recommendations have been developed and implemented to ensure safety and mitigate this
impact to standard values and below. These recommendations did not interfere with the development,
therefore, in the immediate vicinity of the developed area of the field, residential neighborhoods with
multi-storey residential buildings and buildings of related social infrastructure were built. On the
territory of the industrial site, buildings and structures subject to protection were also examined, among
them are administrative and amenity plants, mine copra and others. Methodological recommendations
were developed for each registered object.

Nowadays, it has again become relevant to carry out studies of the seismic effect, which negatively
affects the structures of buildings and structures, due to a number of factors:

- More and more often in the field of subsoil use, scientifically grounded requirements began to
be applied in the framework of the environmental safety of blasting operations, as a result of
which the seismic effect of industrial explosions began to attract the attention of the city
administration of Nizhny Tagil and public organizations;
- The conditions for the development of the deposit by the underground method changed: there
were more mine floors, which entailed a change in the location of the explosion center, the
physical properties of rocks in the underground workings changed, which increased the number
of lines of least resistance and therefore it became necessary to use more powerful charges;
- Mining and geological conditions have changed, not only at the mining site, but also along the
path of propagation of seismic waves, the geomorphological features of ores have changed, as
well as the elements of their occurrence;
- In the light of established market relations, the use of previously ubiquitous explosive materials
has become unprofitable;
- New explosive materials appeared, with more modern physicochemical properties, therefore,
the explosions excited seismic waves with amplitudes much larger than before, vibration began
to be felt much stronger in buildings and just on the surface;
- To no less extent, the changes also affected the processes of charging wells, since the use of
new explosive materials entailed changes in the charging technology and the corresponding
mechanisms and devices.

2. Materials and methods
The first thing that needs to be done for high-quality registration of seismic waves, excited by a
technological explosion, is to choose the right installation points for seismic receivers at the surveyed
object and near it. At object 1 (residential building), in one of the walls of which a vertical crack was
formed, the geophones were installed in accordance with the tectonic fault - on both sides, opposite each
other, in the direction of the seismic effect registration. Three-component seismic receivers GS-20DX
[3] were used, as is known, such a device registers 3 components of oscillations - the speed of natural
and forced displacements of the surveyed objects and the amplitude of these displacements.

To register seismic vibrations in a multi-storey building (object 1), a scheme was chosen in which
each geophone is located one above the other on each floor on the same line. Further, the devices were
installed in the ground near the building, which is necessary for comparative analysis. To carry out
observations on the ground, the geophones were installed in groups of 3 instruments, which were
oriented along the X component - with its help vibrations along the seismic beam were recorded, one
for recording vibrations across the seismic ray - Y, and one for recording the vertical component of
vibrations - Z. When registering in buildings, the instruments were oriented along the directions of the
main axes of the buildings. In this case, the X component corresponded to the longitudinal axes of the buildings. When installed on the ground near a building, in the orientation of the instruments, for convenience, the building axes are usually given priority over the seismic beam [4].

The registration result is influenced by many simultaneously acting factors. In order to minimize the influence of variable factors, a number of conditions were observed in the study. To install geophones inside the building, a horizontal platform is selected on the floor, mainly a concrete surface, instruments are placed along the registration lines. When installed outdoors, the site is asphalt or dense soil. The equipment and cables used must be protected from weather conditions, extraneous vibrations and other factors that can negatively affect the process of recording seismic vibrations [5]. The measuring equipment must be grounded to avoid industrial interference (for example, the most likely interference is from 50 Hz mains). After placing all the necessary sensors, the measuring system starts to register the explosion. Registration takes place automatically.

The digital records were processed [6] as follows. Since the capabilities of the measuring system used make it possible to record almost unlimited duration, the start of seismic data recording began in advance, from 5 to 15 minutes before the explosion, after the explosion, the technological interval was also observed. As a result, the parts necessary for study were cut out from the record.

Then the seismogram was examined channel by channel. The received signal was digitally filtered to extract the frequency spectrum of the signal. This is done using the Fast Fourier Transform (FFT) algorithm [7]. The dominant frequency extracted from the spectrum using this algorithm is taken for further research. Further, the signal is removed, as practice shows, with a frequency of generally more than 20 Hz. The value of the filtered frequency is chosen in a particular way due to the fact that with increasing depth the prevailing frequency increases. After digital filtering, the value of the deviation amplitude of the functional part of the seismic receiver is determined. The sought value is measured as the difference between the adjacent minimum and maximum values of oscillations, then its maximum value is used.

The following formula was used to calculate the highest displacement velocity at the control point:

\[ V = \frac{A}{K \times 100} \times 10^{-3} \text{ cm/s} \]  \hspace{1cm} (1)

Where A – highest amplitude deviations, K - conversion coefficient.

Coefficient K is determined by the type of the geophone, usually it is indicated in the instrument's passport data or is determined experimentally by comparison with the reference instrument.

The maximum displacement at the registration point was determined by us using the following formula:

\[ S = \frac{V}{2\pi f}, \mu m \]  \hspace{1cm} (2)

Where f is the prevailing frequency.

In the case when the registration at one point is carried out using three field components - in the X, Y and Z directions, then the total values of the maximum displacement and displacement velocities are determined by the following well-known formulas:

\[ V_x = \sqrt{V_x^2 + V_y^2 + V_z^2} \]  \hspace{1cm} (3)

\[ S_x = \sqrt{S_x^2 + S_y^2 + S_z^2} \]  \hspace{1cm} (4)
calculation according to formulas 3 and 4, the values are maximum, since the largest total values of speed and displacement are used to determine them. In reality, the instantaneous total values of the displacement and displacement rates turn out to be lower than the calculated ones.

3. Results and discussion
Seismic monitoring was carried out in 3 stages, each stage about a month after the previous one. According to the Methodological Guidelines for Seismic Safety of Industrial and Social Infrastructure Objects from Technological Explosions at the Magnetitovaya Mine, the permissible displacement rate for multi-storey panel buildings is 1.5 cm/s, and for small-piece masonry buildings this parameter is limited to 2 cm/s.

When registering an explosion at the first stage near a five-story residential building (object 1), it was calculated that the values of displacement velocities are in the range of 0.062–0.413 cm/s per channel or 0.148–0.590 cm/s for the total values for three components.

At the second stage, when registering at the entrance of a building (object 1), the values lie within the range of 0.062–0.239 cm/s per channel or 0.253–0.312 cm/s for the total values for the three components. Object 2 (residential building) is closer to the shot point than object 1, therefore the recorded values of displacement velocities are slightly higher here. Values for individual channels are in the range of 0.051–0.758 cm/s. Three-component values are in the range of 0.164–0.946 cm/s.

At the third stage of registration with the ground installation of geophones at object 1, the results were obtained: channel by channel - 0.134–0.511 cm/s, total for three components - 0.271-0.612 cm/s.

Thus, it can be seen that for object 1 (panel building) the obtained values are no more than 41% of the standard, and for object 2 (brick building) - no more than 48%.

The three technological explosions considered were recorded at three different points. Explosions at the first and third stages were registered near object 1. The explosion at the second stage was registered near the object 2 and floor by floor in one of the entrances of the object 1.

Thus, the “Methodological Guidelines for Ensuring the Seismic Safety of Industrial and Social Infrastructure Objects from Technological Explosions at the Magnetitovaya Mine”, drawn up in 2006, does not lose its relevance.

4. Conclusion
Based on the measurements performed, it can be concluded that at present, the production of technological explosions in the Magnetitovaya mine in compliance with all established standards does not have a dangerous effect on the buildings of Nizhny Tagil city, located at relatively short distances from the Magnetitovaya mine.

The maximum displacement velocities obtained during registration of the seismic effect from three technological explosions [10] do not exceed 40-50% of the current permissible values.

The previously not considered factor of the influence of the tectonic structure of the rock mass on the passage and properties of the seismic waves arising from the explosion requires more careful study.

In order to determine the probable position of disturbed zones, it is necessary to select additional research objects on the territory, both adjacent to the Magnetitovaya mine, and at a greater distance from it in order to determine the possibility of the existence of waveguides that transfer the energy of seismic waves over relatively long distances without significant losses.

The measuring complex used, with the help of which the registration of practically all explosions was performed, justifies expectations and fully corresponds to its purpose. The measurements made allowed us to make some changes in the design of the measuring system, aimed at improving the performance of this equipment.

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