The study of seismic effects and shock air waves during a large-scale blast at the Ust-Katavskiy granite quarry

Pavel Menshikov[1*], *Semen* Taranzhin [1], and *Alexander* Flyagin[1]

[1] Institute of Mining Engineering of the Ural branch, Russian Academy of Sciences, 620075, 58, Mamina-Sibiryaka st., Ekaterinburg city, Sverdlovsk Region, Russia

Abstract. The analysis of the values of the permissible speed of seismic vibrations and the calculation of the limiting values of short-term vibration at the base of the protected objects of Ust-Katav town and the settlement of Maliy Berdyash are carried out. Instrumental measurements of the speed of seismic vibrations of soil and pressure at the front of an air shock wave (air blast) during a large-scale blast in a quarry of building stone (dolomites) of «Ust-Katavskiy Granite Quarry» LLC (UKGK) were carried out in order to determine and evaluate safe seismic and shock air the impact of blasting on residential buildings in the settlement of Maliy Berdyash and the building of a special comprehensive boarding school in the Ust-Katavskiy urban district of the Chelyabinsk region. The conditions for blasting that provide seismic safety of protected objects are determined.

1 Introduction

The quarry of building stone (dolomites) of UKGK LLC is located in the north of Ust-Katav town and Maliy Berdyash settlement. The blasting front at the mining enterprise, while mining the southern and southeastern sides, approaches close to residential buildings and office buildings of Ust-Katav and to residential buildings and summer cottages of the settlement of Maliy Berdyash, which are located outside the mining allotment and the explosive danger zone works on a quarry of building stone (dolomites). In order to ensure the seismic safety of the protected objects from large-scale blasts, in 2019 instrumental measurements of the actual maximum speed of seismic vibrations of soil and pressure were carried out at the air-blast front near the four-story special boarding school of the Ust-Katavskiy urban district of the Chelyabinsk region (Stroiteley str., D. 5, Ust-Katav town) and one-story barracks-type residential buildings (Tsentralnaya St., 2 and Berezovaya St., 1, Maliy Berdyash settlement) during a large-scale blast at a construction site of stone (dolomite) Ltd. "UKGK".

Based on the conducted instrumental measurements, an assessment was made of the safe level of blasting operations based on the calculated values of the permissible speed of seismic vibrations of the soil (limiting values of short-term vibration) for each guarded

* Corresponding author: menshikovpv@mail.ru

object and the limiting value of permissible overpressure at the air-blast front. As a result, design decisions were confirmed on the safety of the seismic effect of the explosion and the impact of shock air waves on residential buildings and the building of a boarding school during blasting operations in cramped conditions.

The main criterion for the safety of seismic impact on protected objects on the earth's surface, as well as when exploding in underground conditions, is the permissible rate of soil vibrations at the base of the protected objects, which ensures the complete absence of any damage. The permissible speed of seismic vibrations depends on many factors, the main of which are: the condition of the protected objects, their design, the quality of building materials, physical deterioration, purpose and service life.

Many authors in their writings note that mainly in buildings and structures damage does not occur at oscillation speeds up to 3-5 cm / s [1-10]. At speeds greater than 5 cm / s, plaster shedding occurs and small hair cracks begin to appear in light partitions [11]. Also, some authors note that the critical speed of seismic vibrations during multiple explosions in open pits is assumed to be 3 cm / s for residential buildings [12, 13]. For example, Kartuzov M. I. notes that for buildings made of brickwork up to 5 floors high and for all types of residential and public buildings with multiple large-scale blasts, the permissible speed of seismic vibrations is 3 cm / s [14].

The calculation of the permissible speed of seismic vibrations was carried out according to the method of GOST 52892-2007 “Vibration and shock. Vibration of buildings. Measurement of vibration and assessment of its impact on the structure” [15] depending on the type of soil at the base of the structures, the type and design of structures, the material of the structures, the type of foundation, the distance between the vibration source and its measurement location and the type of vibration source.

$$V_{per} = V_0 \cdot F_g \cdot F_b \cdot F_d \cdot F_k \text{, mm / s} \quad (1)$$

where V_0 – reference speed value equal to 20 mm / s;
F_g – correction for the type of soil;
F_b – correction for the type of structure. $F_b = k_b \cdot k_m \cdot k_f$;
k_b – correction for the type and design of the structure;
k_m – correction for the material of the structure;
k_f – correction for the type of foundation;
F_d – distance correction for different vibration sources;
F_k - correction for the type of vibration source.

The calculation results according to the methodology of this GOST are presented in table 1. The limiting value of short-term vibration was 3.25 cm / s for the building of a boarding school; 2.88 and 3.46 cm / s for residential buildings of the barracks type in the Maliy Berdyash settlement, which are located in the immediate vicinity of the blasting zone in the southern and southeastern sections of the building stone quarry (dolomites) of UKGK LLC.

Table 1. Characteristics of protected objects and calculation of permissible speed of seismic vibrations

Indicators	Protected objects - public building, residential buildings		
	4-floor special boarding school of the Ust-Katavsky urban district of the Chelyabinsk region (Stroiteley St., 5, Ust-Katav) – p. 1.	One-story barrack type residential building (st. Tsentralnaya, 2, Maliy Berdyash settlement) - p. 2.	One-story barrack type residential building (st. Berezovaya, 1, Maliy Berdyash settlement) - p. 3.
	High-rise civilian building with a large crowd of people	Barracks with small crowds	
Object Status	Small cracks in foundation and aggregate		
Type of soil	Rocky and semi-rocky soils (dolomites)	Solid boulder clay, compacted crushed stone	
Type of construction	High-rise civil building	Conventional building	
The main material of the structure	Brickwork	Brickwork	Wood
Type of foundation	Pile stand	Solid foundation	
The distance between the source of vibration and the place of measurement	more than 200 m		
Type of vibration source	Blasting		
F_g k_b k_m k_f F_d F_k	2.5 0.65 1.0 1.0 1.0 1.0	1.8 1.0 1.0 0,8 1.0 1.0	1.8 1.0 1.2 0.8 1.0 1.0
Limit value of short-term vibration, cm / s (mm / s)	**3.25** (32.5)	**2.88** (28.8)	**3.46** (34.56)

2 Materials and methods

The method of multichannel registration of mechanical vibrations for measuring seismic parameters was carried out with recording on digital seismic recorders URAN (LLC Gorizont, Russia, Ekaterinburg city) [16] and MiniMate Plus (Instantel, Canada, Ontario) [17] (Fig. 1, 2).

The speed of seismic vibrations of the soil was recorded along three components (axes): longitudinal - x, transverse - y and vertical - z.

$$\mathbf{V} = \sqrt{\mathbf{V_x^2} + \mathbf{V_y^2} + \mathbf{V_z^2}}, \text{ cm / s} \quad (2)$$

where $\mathbf{V_x}$, $\mathbf{V_y}$, $\mathbf{V_z}$ – maximum vector values of the speed of seismic vibrations of the soil along the longitudinal, transverse and vertical components, cm / s.

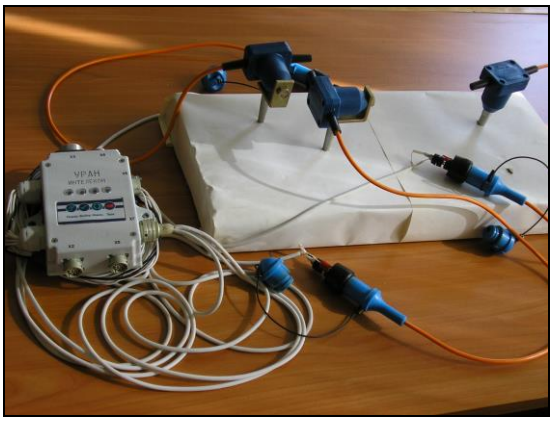

Fig. 1. URAN analog voltage meter and recorder

Fig. 2. MiniMate Plus Digital Seismic Recorder

The speed measurements of the seismic vibrations by the MiniMate Plus seismic recorder were made by the Series III Standard Transducer (Article No. 714A0301), which contains 3 mutually perpendicular seismic sensors with an amplitude measurement range from 0.005 (0.0127 cm / s) to 10 inches per second (25.4 cm / s) with a minimum resolution of 0.005 (0.0127 cm / s) inch, with a frequency range from 2 to 300 Hz and a sensitivity of 0.16113 V / inch / s (0.0006344 V / cm / s). The seismic receiver was installed in the ground near the foundation of a residential building using 3 pins and was oriented by the arrow in the direction of the mass explosion.

The measurements of the speed of seismic vibrations by URAN seismic recorders were carried out using three GS-20DX seismic sensors with a sensitivity of 0.276 V / cm / s, which were installed in the ground near the foundation of a residential building and a boarding school building using pins and oriented in three directions relative to the large-scale blast .

The pressure at the front of the shock-air wave (air-blast) was determined by a MiniMate Plus seismic recorder using a Series III L Microphone linear microphone (Code No. 714A0401) for measuring pressure in the far zone, with a pressure measuring range from 0.5 to 500 Pa with a minimum resolution 0.25 Pa and sensitivity 0.003223 V / Pa, mounted on a tripod near the guarded object and oriented in the direction of the large-scale blast. The line microphone was mounted on a tripod 1 m high.

According to the results of measurements of the speed of seismic vibrations of the soil and air-blast using the software BlastWare III and uran.exe on the computer, the calculated values in the dynamics of the process were determined [18].

The sites for measuring the speed of seismic vibrations of soil and pressure at the air-blast front during a large-scale blast at a quarry of building stone (dolomites) of UKGK LLC are shown in Fig. 3 - 5.

Fig. 3. The location of the URAN seismic recorder near the 4-floor special boarding school of the Ust-Katavskiy urban district of the Chelyabinsk region (5 Stroiteley St., Ust-Katav town) - p. 1.

Fig 4. The location of the URAN seismic recorder near a one-story barrack type residential building (2 Tsentralnaya St., Maly Berdyash settlement) - p. 2.

Fig. 5. The location of the MiniMate Plus seismic recorder near a one-story barrack type residential building (1 Berezovaya St., Maliy Berdyash settlement) - p. 3.

Location map with the location of the blasting block No. 08, level +356 m in the quarry of building stone (dolomites) of UKGK LLC and measuring points: 4-floor special boarding school of the Ust-Katavskiy urban district of the Chelyabinsk region (5 Stroiteley St., Ust-Katav town) and one-story residential houses of a barrack type (2 Tsentralnaya St. and 1 Berezovaya St. of Maliy Berdyash settlement) are shown in Fig. 6.

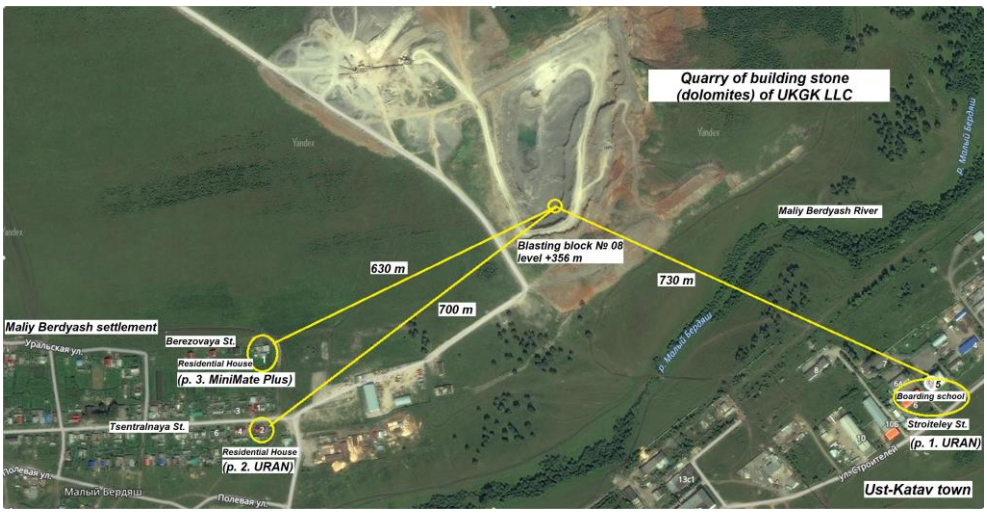

Fig. 6. Terrain layout with the location of the blasting block No. 08, level +356 m in the quarry of building stone (dolomites) of UKGK LLC and measuring points: 4-floor special boarding school of the Ust-Katavskiy urban district of the Chelyabinsk region (5 Stroiteley St., Ust-Katav town) (p.1) and one-story barracks-type residential buildings (2 Tsentralnaya St. and 1 Berezovaya St. of Maliy Berdyash settlement) (p.2 and 3).

3 Results

The results of measurements of the speed of seismic vibrations and air-blast are presented in table 2.

Table 2. The results of instrumental measurements of parameters of seismic vibrations and air-blast during blasting in the quarry of building stone (dolomites) of UKGK LLC (blasting block No. 08, level +356 m)

Explosion date (explosion time, hour)	Place of measure-ment; seismic recorder (measu-ring point)	Maximum pressure at the front of the air-blast, Pa	Maximum speed of seismic vibrations of the soil (limiting value of short-term vibration), cm / s				Maximum mass of simultane-ously explosive charge in deceleration stage, kg	Distance from the place of the explosion to the place of measure-ment, m
			V_x	V_y	V_z	V		
23.04.19 (13:45)	Boarding school; URAN (p.1)	-	-	-	-	-	762	730
	House (2 Tsentral-naya St.); URAN (p.2)	-	0.13	0.1	0.06	0.17	762	700
	House (1 Berezo-vaya St.); MiniMate	6.25	0.1	0.1	0.08	0.16	762	630

	Plus (p.3)							

Near a 4-storey special boarding school in the Ust-Katavskiy urban district of the Chelyabinsk region (5 Stroiteley St., Ust-Katav town) during a large-scale blast, the URAN seismic recorder did not record the speed of seismic vibrations of the soil, because the actual speed was below the sensitivity threshold of the GS-20DX seismic sensors. The location diagram (Fig. 6) shows that between the quarry and the Ust-Katav town there passes the Maliy Berdyash River, at the base of the channel of which there are sedimentary rocks, which are a natural screen that dampens seismic vibrations.

The recorded values of the maximum resulting velocity of seismic vibrations of the soil did not exceed the permissible speed calculated for each object (Table 2) and amounted to 0.17 and 0.16 cm / s near the foundation of one-story barracks-type residential buildings (2 Tsentralnaya St. and 1 Berezovaya St., Maliy Berdyash settlement), which are 17 and 21.5 times less than the permissible speed, respectively. As a result, seismic safety of protected objects is ensured.

The recorded values of the maximum overpressure at the air-blast front near the barracks-type residential building (1 Berezovaya St., Maliy Berdyash settlement) are much lower than the permissible value. According to the Federal Rules and Regulations on Industrial Safety: Safety Rules for Blasting Operations [19], the maximum permissible value of the overpressure at the air-blast front for glazing is 2 kPa.

4 Conclusions

1. Blasting work carried out on April 23, 2019 in the quarry of building stone (dolomites) of UKGK LLC (blasting block No. 08, level +274 m) was performed by Promvzryv LLC organization with the provision of seismic safety and the safety of impact air large-scale blasts. They do not adversely affect protected objects located in the immediate vicinity of the blasting zone: a special general boarding school of the Ust-Katavskiy urban district of the Chelyabinsk region (5 Stroiteley St., Ust-Katav town) and barracks-type residential buildings (2 Tsentralnaya St. and 1 Berezovaya St., Maliy Berdyash settlement).
2. An analysis of the components of the wavefront of the seismic wave shows that in the far zone (more than 100 m) surface waves prevail in intensity, where the components of seismic vibrations are distributed along the x, y, z axes approximately equally. Barracks-type residential buildings are located in the far zone and belong to low-rise buildings; in such buildings, even with a vibration speed of up to 10 cm / s, basically no damage is observed.
3. Actual overpressure at the air-blast front from large-scale blasts in a quarry may differ depending on climatic and meteorological conditions (temperature, atmospheric pressure, relative humidity, wind speed and direction). At high wind speeds of more than 5 m / s, its direction must be taken into account. If the wind is directed towards residential buildings or a boarding school in Ust-Katav town, then a large-scale blast must be postponed [20].
4. In winter, at negative air temperatures, in frozen soils at the base of protected objects and frozen rocks in the quarry, as well as in the summer with high humidity and watered rocks, it is recommended to carry out additional instrumental measurements to clarify safe values of the speed of seismic vibrations soil and overpressure at the air-blast front.
5. With an increase in depth and an expansion of the building stone (dolomite) quarry of UKGK LLC, when the mining front approaches a distance of less than 630 meters to protected objects, the real values of the actual speeds of seismic vibrations at the base of the foundation of buildings and structures, as well as shock propagation conditions air waves can change, at this stage it is recommended to carry out instrumental measurements to confirm safe values of the speed of seismic vibrations of the soil and excess pressure at the front of the shock wave.

Acknowledgments

The authors are grateful to Sergey Nikolaevich Zharikov, head of the Laboratory for Rock Destruction, Institute of Mining Engineering, Ural Branch of the Russian Academy of Sciences, for his help in organizing the research.

The studies were carried out as part of State Assignment No. 075-00581-19-00, Topic No. 0405-2019-0005 (2019 - 2021), as well as with the additional attraction of contractual funds.

References

1. V. I. Bashkov, A. A. Eremenko, I. V. Mashukov, GIAB J., **2**, 160-171 (2016)
2. S. N. Zharikov, G. P. Bersenev, V. A. Kutuev, A. S. Flyagin, Problemy nedropol'zovaniya, **3 (22)**, 145-154 (2019)
3. V. I. Kulikov, M. I. Ganopolsky, Vzryvnoye delo, **121-78**, 135-153 (2018)
4. P. V. Menshikov, Methodology for assessing the impact of seismic safety and the impact of an air shock wave in the quarries of the Urals, *Tekhnologiya i bezopasnost' vzryvnykh rabot*, 211-218 (2011)
5. A. G. Novinkov, S. I. Protasov, P. A. Samusev, A. S. Tashkinov, Vestnik KuzSTU, **6 (118)**, 56-62 (2016)
6. M. S. Tokmantsev, GIAB, **S4-2**, 181-187 (2015)
7. T. Hudaverdi, O. Akyildiz, Environ. Earth Sci., **76 (3),** 138, (2017)
8. H. Nguyen, X. N. Bui, C. Drebenstedt, D. T. Bui, NRR J, (2019)
9. P. K. Singh, M. P. Roy, R. K. Paswan, R. K. Dubey, C. Drebenstedt, Int. J. Rock Mech. Min. Sci., **80**, 79-88 (2015)
10. J. Xu, Y. Kang, X. Wang, G. Feng, Z. Wang, Int. J. Rock Mech. Min. Sci. T. **119**, 156-167 (2019)
11. B. N. Kutuzov, Safety blasting in industry, 544 (Moscow, Nedra Publ., 1992)
12. A. S. Volokh, The basics of controlling the action of an explosion using shielding, 224 (Moscow, Nauka Publ., 1986)
13. Y. I. Tseytlin, N. I. Smoliy, Seismic and shock air waves of industrial explosions, 192 (Moscow, Nedra Publ., 1981)
14. M. I. Kartuzov, Methodology for providing seismic-safe blasting technology, IME MFM USSR, 12 (Sverdlovsk, 1984)
15. GOST R 52892-2007, Vibration and shock. Vibration of buildings. Measurement of vibration and assessment of its impact on the structure (GOST - State Standard, Russian National Standard), 16 (M.: Standartinform, 2008)
16. Operation manual “URAN-INTELEKON analog voltage meter and recorder (AVMYu.411116.012 RE), 58 (2006) (in Russian)
17. MiniMate Operator Manual, Instantel, Canada, Ontario, 43 (2001)
18. Methods of measuring the speed of seismic vibrations and pressure at the front of a shock air wave using a MiniMate Plus digital seismic recorder, a URAN registration and analysis device, and an autonomous AIR-meter. STO 01.01.001 – 2011 (Standard of Organization), IME UB RAS, 15 (Ekaterinburg, 2011)
19. Federal norms and rules in the field of industrial safety. Blasting safety rules. Edition 2, rev. and add. (Order No. 581 of November 30, 2017), 235 (Moscow, 2013)

20. B. N. Kutuzov, Bezopasnost' vzryvnykh rabot v gornom dele i promyshlennosti: uchebnoye posobiye, Safety of blasting in mining and industry: a training manual, 671 (Moscow: Gornaya kniga, 2009)