Utilization of field seismometers for measuring the paraseismic vibrations of mining blasts

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Abstract. The Hrabuvka Quarry was one of the quarries on which the seismic effects were measured when performing large-scale blasting operations – bench blasting. These measurements were carried out as part of a university project to investigate further unfavourable seismic effects of blasting operations with respect to the type of ignition and explosives used. The aim of this article is to determine whether during the large-scale blasting operations from April to June 2019 vibration speed values were measured, which could have adverse effects on quarry structures and to propose a suitable solution to reduce these values, for example by changing the type of ignition from non-electric to electronic and by changing the ignition timing of individual charges.

1. Introduction
Blasting has always been and certainly will be the most efficient way of extracting certain minerals, and it is used with equal importance in other industries. All these sectors face the same problem; except for the spread of mined material and an air (or shock) wave, the problem is mainly represented by adverse seismic effects of blasting work.

This article primarily deals with the peak values of the oscillation amplitudes, evaluates blasting work from the point of view of legislation and creates the basis for the following research on reducing seismic effects through timing changes, adjustments of charges to split or gap charges, etc.

The measurement was carried out using two autonomous seismic devices BRS 32. It is a battery device with a three-component seismic geophone and recording on internal flash memory with a capacity of up to 32 GB. Downloading data and other parameters are configurable via USB interface. These instruments were placed in horizontal profiles of the quarry, always at different distances and always near one of the important quarry structures. The measurement results, i.e. vibration velocities acting on the structures, will be evaluated according to the standard CSN (Czech National Standard) 73 0040. The values obtained from the individual measurements can subsequently serve the company Ceskomoravsky sterk (Czech-Moravian Gravel) not only as a check measurement but also as a basis for VSB – Technical University of Ostrava in the following research, which compares the adverse effects...
of seismic activity of various types of ignitions used in blasting operations. The measurement result does not anticipate exceeding the load limits for structures according to the standard CSN 73 0040, because blasting works at the quarry have a long and trouble-free tradition. However, as described above, these measurements will serve to research and further improve blasting technology by adjusting the timing of detonations.

Figure 1. Measuring apparatus BRS32.

2. State-of-the-art
At present, the still persistent problem of blasting is seismic influences on the environment. For this reason, experimental measurements of blasting work are performed under different conditions, and the measured values are then analysed using methods such as FFT, M-P and others. In the past, a number of researches have already been carried out in order to determine the best conditions for reducing the negative seismic effects of blasting [5]. With the ability to program the shot timing for each individual detonator to an accuracy of 1 ms, electronic detonators are preferably used in combination with many other indicators, such as split charges in bores, well-established detonation pattern, geology, differences in charge weights and more. As already mentioned in the above-mentioned work, despite the amount of research, the question of timing and the combination of other aspects is still an unexplored territory to some extent.

3. Hrabuvka Quarry
The Hrabuvka Quarry is one of the Moravian quarries of the company Ceskomoravsky sterk, a.s. The plant is located in Moravia about 5 km northwest of the town of Hranice. The mined raw material is Moravian greywacke.

The products can be used in concrete, reinforced concrete, prestressed concrete, prefabricated elements, waterproofing concrete, cement concrete road pavements, for railway construction, for road
construction - in asphalt layers, unbound layers, mechanically reinforced aggregates, underfills and backfills, under interlocking pavement and other specific applications. The production of mechanically reinforced aggregates (abbreviation MRA) uses the most modern technology in the Czech market. The MRA is suitable for reinforcing forest and agricultural roads, for cycle paths, and it can also be used as a base layer on construction sites, playgrounds and under parking areas.

Mining has been taking place since 1900. Mining of the raw material is carried out on seven levels with a length of about 1 km and a width of 400 m.

The best quality raw material of the deposit is greywacke, which accounts for about one-third of the deposit. The remaining volume consists of rocks of flysch character when the proportion of greywacke, siltstones and silty shales alternately changes. The greywacke is predominantly fine-grained to medium-grained. From the point of view of the distribution of rocks in the quarry, there are conglomerates of medium-grained to the coarse-grained thickness of about 15 meters in the overburden. The core of the deposit area is formed by greywacke of thickness ranging from 40 to 50 meters, and the bedrock contains 120 m thick flysches.

3.1 Quarry drainage
As for the drainage of the quarry, the block of rocks drains into the lake in the flooded part of the quarry. From there, the groundwater infiltrates through a disrupted rock mass and rises in the spring area of the Radikovsky brook at an elevation of 290 m above sea level.

Water seepage through cracks of the rock mass together with rainwater is the primary source of mine water. The water from the lake is used in the production technology for sprinkling sections with increased dustiness, for washing fraction 4/8 and for the sprinkling of roads. The technology of crushed aggregate processing is designed as a dry technology.

Since the water consumption for aggregate production is approximately half of the inflow of water into the lake, it is necessary to drain the water. Another reason for pumping is the flooding of the elevation of 290 m above sea level, where mining has been carried out since 2015.

3.2 Reserves in the deposit
In the locality of Hrabu vka Quarry, there are greywackes, siltstones, conglomerates, slate and flysch with varying proportions of greywacke, dust and slate. These rocks have very similar technological properties; therefore, the raw material is divided into material suitable only for the production of crushed aggregates and rocks unsuitable for the production, which is the so-called quarry waste.

The amount of raw material that is not suitable for the production of quality crushed aggregates is about 3% of the volume of the deposit. Siltstone and clay slate represent materials with worse technological properties than conglomerates and greywacke; therefore, they were considered as a pollutant in the past. At present, they are considered as a raw material with possible use for less demanding structures. For this reason, pollution is considered to be zero. [3]

In the past, several mining surveys were carried out in the Hrabuvka Quarry, estimating the amount of reserves in the deposit.

According to the latest calculations and according to the Annual Statement on the Movement and State of the Reserves of Exclusive Mineral Deposits for 2012 (GEO V-3-01), as of 31 December 2013, the Hrabuvka Quarry had a total of 13,867,000 m³ of the raw material exploitable reserves. [3]

4. Seismic activity evaluation
One of the main tasks of current seismic research is to assess the seismic threat to sites where important industrial buildings (nuclear power plants, nuclear waste repositories, chemical plants, high-rise buildings, tunnels, underground reservoirs, etc.), historical buildings or significant natural areas (e.g. mineral water resources, geothermal resources) are located. Seismic threats can be caused by natural
seismicity, induced by seismic events (in the Czech Republic, mainly blasting works) and technical sources, especially by larger blasting works. The Czech lands belong to the area of so-called mild seismic activity, which is characterized by the Map of Seismic Regions according to current European and Czech standards. In Bohemia, the most seismically active area in West Bohemia is the Hronov-Poric fault in the Nachod area and Ostrava area. [4]

4.1 Seismic effects of blasting operations

Assessment of seismic load acting on structures is often based on the measurement of vibrations at the reference site. Seismic effects are governed by the standard CSN 73 0040, formerly CSN EN 1988 (CSN 73 0036). [5]

The task of assessing the seismic loads acting on structures is to determine a safe limit that does not damage the structure or loosens the rock. Special assessments are needed for typical structures: earth structures on embankments, underground structures, structures on terrain with high groundwater (over 1 m), tanks, tunnels, etc. The intensity of loading depends on the nature of the source of vibration (blasting operations, large explosions, traffic, etc.) the nature of the vibrating object (weight, foundation conditions), geological conditions. [5]

Official measurement is also an essential part of seismic effects. Official measurements include evaluation of vibrations according to CSN 73 0040, i.e. the effect of vibrations acting on structures, mathematical analysis, evaluation of oscillation path and acceleration.

The result of the measurement is a recommendation for further driving technology with possible modification of blasting works and limit charges, the proposal of modification of drilling and timing scheme etc. Evaluation can be done by a person authorized by the blasting technical manager or an expert in blasting works and seismic engineering activities. [6]

5. Realization of measurement

The measurement at the Hrabuvka quarry was carried out in total at three mining shots on two different BRS32 measuring apparatuses. Primarily, the vibration speed acting on the quarry structures during mining shots was measured in order to detect any adverse effects that may be caused by blasting works on quarry structures. For this measurement, two autonomous BRS32 apparatuses are equipped with LE3D sensors were used. The SM6 geophones with a sensitivity of 28.8 mV.mm⁻¹.s⁻¹ are used for sensing high vibration velocities (up to v = 72 mm.s⁻¹). Measuring devices were placed to the most important objects within the quarry, such as a workshop, weighing machine, primary shredder, office building, substation or sanitary facilities building.

6. Results of measurements at the Hrabůvka Quarry

In the case of the first mining blast to be measured performed at the quarry on 26 April 2019, the measuring apparatuses were located at two different locations - the Workshop site (measured at the distance of 806 m, Fig. 2,4,7) and the Dispatching Weighing Machine site (measured at the distance of 921 m, Fig. 3,5,6).
Figure 2. Z-axis vibration speed at the blast on 26 April 2019, Site: Workshop.

Figure 3. Z-axis vibration speed at the blast on 26 April 2019, Site: Dispatching Weighing Machine.

Figure 4. N-axis vibration speed at the blast on 26 April 2019, Site: Workshop.

Figure 5. N-axis vibration speed at the blast on 26 April 2019, Site: Dispatching Weighing Machine.

Figure 6. E-axis vibration speed at the blast on 26 April 2019, Site: Workshop.

Figure 7. E-axis vibration speed at the blast on 26 April 2019, Site: Dispatching Weighing Machine.
The second measurement took place on 2 May 2019 and again at two sites - the Office Building site (646 m distance from the shot, Figures 8, 10, 12) and the Primary Shredder site (308 m distance from the shot, Figures 9, 11, 13).

**Figure 8.** Z-axis vibration speed at the blast on 5 May 2019, Site: Primary Shredder.

**Figure 9.** Z-axis vibration speed at the blast on 5 May 2019, Site: Office Building.

**Figure 10.** N-axis vibration speed at the blast on 5 May 2019, Site: Primary Shredder.

**Figure 11.** N-axis vibration speed at the blast on 5 May 2019, Site: Office Building.

**Figure 12.** E-axis vibration speed at the blast on 5 May 2019, Site: Primary Shredder.

**Figure 13.** E-axis vibration speed at the blast on 5 May 2019, Site: Office Building.
The third measurement took place at the blast performed on 29 May 2019 at two sites. The first site was established at the location of the quarry sanitary facilities building, which was 692 m from the blasting site (Figs. 14, 16, 18). The second site was determined at the quarry substation, and its distance from the blasting point was 601 m (Figs. 15, 17, 19).

**Figure 14.** Z-axis vibration speed at the blast on 29 May 2019, Site: Substation.

**Figure 15.** Z-axis vibration speed at the blast on 29 May 2019, Site: Sanitary Facilities Building.

**Figure 16.** N-axis vibration speed at the blast on 29 May 2019, Site: Substation.

**Figure 17.** N-axis vibration speed at the blast on 29 May 2019, Site: Sanitary Facilities Building.

**Figure 18.** E-axis vibration speed at the blast on 29 May 2019, Site: Substation.

**Figure 19.** E-axis vibration speed at the blast on 29 May 2019, Site: Sanitary Facilities Building.
7. **Discussion and conclusion**

During the measurements at the quarry, we collected enough data to evaluate possible undesirable seismic effects of blasting operations on the surroundings. The first measured blast took place on 26 April 2019 – during this blast, the workshop building and dispatching weighing machine were measured. The highest vibration speed at both of these sites was recorded on the N-component, reaching $V_n = 1.181$ mm.s\(^{-1}\) for the workshop building and $V_n = 0.868$ mm.s\(^{-1}\) for the dispatching weighing machine. In the case of the measurement, which took place on 2 May 2019, it was measured relatively close to the blast, at a distance of 309 m in the case of the primary shredder and 646 m in the case of the quarry office building. At the primary crusher site, the highest values were measured on the N-component, namely $V_n = 4.212$ mm.s\(^{-1}\), and in the case of the office building, it was in the Z-component, and the vibration speed reached $V_z = 1.403$ mm.s\(^{-1}\). The last measurement took place on 29 May 2019 at the quarry substation at 601 m and the social buildings at 692 m. When measuring at the quarry substation site, the highest vibration value at Z-component was reached, namely $V_z = 1.075$ mm.s\(^{-1}\). In the case of the sanitary facilities building, it was $V_z = 0.372$ mm.s\(^{-1}\). The measured data and their visual comparison can be seen in Figure 20.

None of the measurements exceeded the limits of adverse effects on the buildings, even in the case of measurements at the sites relatively close to the blast (308 m).

Interestingly, however, in the case of measurements at the sites with the greatest distance from the blast (the workshop - 806 m, the dispatching weighing machine - 921 m), slightly higher measured values were slightly higher than at the sites that were much closer to the blast (the office building - 646 m, the quarry substation - 601 m, the sanitary facilities building - 692 m) see Fig. 19. This may be due to geology or crossing a nearby road, which can distort the waveform. This may also be explained by the fact that it is at these sites that they achieve the highest vibration values in the Z-components, unlike other sites where the highest vibration speeds are in the N-components.

The measured data will be consulted with the relevant blasting technical manager and quarry management for possible improvement of the blasting technology used.
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