Mine Blasts in the Aru-Lõuna Limestone Quarry – a Multidisciplinary Study Using Seismology and Mining Engineering

Merike Ring¹, Margus Noška², Heidi Soosalu¹,², Ingo Valgma¹, Riho Iskiil¹
¹Tallinn University of Technology (Estonia), ²Geological Survey of Estonia
ring.merike@gmail.com

Abstract – The thesis topic is “Blasting parameters, seismic data analysis and their correlation in Estonia”. The thesis focuses on blasting related to mining of oil shale and limestone, as they are the most important mineral resources mined in Estonia.

This article describes a case study in the framework of the general research topic, focusing to the Aru-Lõuna (Aru-South) limestone quarry in the Ida-Virumaa county.

I. INTRODUCTION

Currently in Estonia, blasting operations are regulated by the Explosive Substance Act and by the regulation “Requirements on blasting projects”. It is important to consider local geological conditions that have an effect on seismic vibration.

Around 120 blasts are carried out in Aru-Lõuna yearly, but the amount of explosives used is modest (tens of times lower) in comparison with the NE Estonian oil shale open cast mines, from where seismic events are detected almost daily. Thus, only few of the blasts in Aru-Lõuna are registered by the Estonian-Finnish co-operative seismic network. Observation time period was set from January 2010 to end of July 2012, and there are 12 registered seismic events located as the result of Aru-Lõuna quarry blasts. The tasks was to examine the whole process, ascertain the factors which could affect the blasting result and find the probable solution if possible.

II. DESCRIPTION AND CHARACTERIZATION OF THE ARU-LÕUNA LIMESTONE QUARRY

Aru-Lõuna limestone quarry is located in Andja village of the Sõmeru rural municipality in the West-Viru County. The total area of the mining allotment is 317.34 ha. The main purpose of the quarry is to produce raw material for the cement factory in the Kunda town. In this case, the most important criteria is the composition of limestone - CaO content to be more than 44%, MgO content less than 3.2% and P₂O₅ content less than 0.5% [5]. Such limestone, which is not suitable for using as a raw material for cement, is used for producing construction aggregate.

Technology of Conducting Blasting Operations

Generally, limestone blasting in Aru-Lõuna quarry can be divided into breaking raw material for the cement factory and breaking construction aggregate. In the case of limestone for cement production, blasting is carried out on a 12 - 14 meters high bench and as limestone pieces with maximum size of 0.8 m are considered as oversized, blasting is performed with two rows of holes in order to have a gentler slope. Based on long-term experience, it has been discovered that the most suitable distance between boreholes is 4 m and between rows 3 m. Deceleration of 42 ms between the holes and 65 ms between the rows is used as a delay. Two primary charges are used, one at the bottom and the other on the hole loaded with an explosive, and drill cuttings are used as a material of a 1.8 m long stem.

Blasting with two rows is also used due to chemistry of varying raw material and weather in winter because of the desire to not to blast too much at a time. In case of a bigger deviation in chemical composition, it takes too long to utilize it together with the rock blasted from other places.

A standard plan of the holes and their spacing of the high bench is presented in Fig. 1.

Vertical holes are drilled with a drilling jumbo in case of blasting both benches. A drill bit with the diameter of 102 mm and a drill rod with the length of 3.66 m are used. In case of dry holes EXAN (also ANFO) produced by Lõhketööd OÜ and Orica Eesti OÜ explosives factory is used as an explosive. ANFO is a mixture of ammonium nitrate and diesel. Due to insufficient moisture resistance of ANFO, holes that are filled with water are loaded with Se natel Powerfrag packed emulsion explosive. The explosive is initiated with non-electric percussive and connecting caps of NONEL type produced by the company Exel. A blasting circuit gets an impulse from an electric blasting cap, which is exploded from a safe distance with a capacitor igniter connected with a 300 m long main cable.

The total charge of the block to be blasted is usually 2,000 ± 300 kg. Quantities of the explosive are small, and therefore the whole process is carried out by manpower. The following auxiliary means are used: a knife - for opening packages, a measuring rod - for measuring length of the charge and a spade - for stemming the loaded holes.

Upon explosion, only part of the released energy goes for breaking the rock, the rest goes for losses like heat, shock wave, spattering pieces of rock and creating seismic waves.
III.  SEISMIC EVENTS

Registrations of monitoring seismic stations recorded in January 2010 – end-July 2012 were used as a source dataset in this work. The data are from the Estonian Environmental Monitoring Programme (seire.keskkonnainfo.ee/seireveeb/) and Heidi Soosalu, the seismologist of the Geological Survey of Estonia (pers. comm., 2012). The date, location and magnitude of the seismic events are shown in Table I.

<table>
<thead>
<tr>
<th>Date</th>
<th>Location coordinates</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.03.2010</td>
<td>59.432 E 26.509 N</td>
<td>0.9</td>
</tr>
<tr>
<td>6.05.2010</td>
<td>59.417 E 26.318 N</td>
<td>0.9</td>
</tr>
<tr>
<td>19.07.2010</td>
<td>59.490 E 26.601 N</td>
<td>1.0</td>
</tr>
<tr>
<td>8.09.2010</td>
<td>59.443 E 26.535 N</td>
<td>1.1</td>
</tr>
<tr>
<td>9.11.2011</td>
<td>59.455 E 26.414 N</td>
<td>0.9</td>
</tr>
<tr>
<td>28.12.2011</td>
<td>59.427 E 26.457 N</td>
<td>0.8</td>
</tr>
<tr>
<td>11.01.2012</td>
<td>59.431 E 26.523 N</td>
<td>1.1</td>
</tr>
<tr>
<td>25.01.2012</td>
<td>59.436 E 26.511 N</td>
<td>0.7</td>
</tr>
<tr>
<td>8.03.2012</td>
<td>59.435 E 26.449 N</td>
<td>1.0</td>
</tr>
<tr>
<td>3.07.2012</td>
<td>59.400 E 26.505 N</td>
<td>0.8</td>
</tr>
<tr>
<td>4.07.2012</td>
<td>59.421 E 26.524 N</td>
<td>0.8</td>
</tr>
</tbody>
</table>

The aim was to find a potential regularity between registering the seismic waves due to blasting and explosions of an explosive. During the period under study, the monitoring network registered 12 seismic events in Aru-Lõuna area, with magnitudes of 0.7 – 1.1. The total number of explosions was around 450 during the above-mentioned period.

In order to find out the accuracy of localization and the result of localization of the events with respect to the quarry, Fig. 3 was drawn up on the basis of coordinates in Table I. Unfortunately, current records of the locations of the sites to be blasted are written down only with the accuracy of a sector. An illustrative picture of the sectors of the quarry is provided in Fig. 4.

IV. VIBRATION VELOCITY AND ACCELERATION

The terms vibration velocity and vibration acceleration of particles are used in the chapter of Local Measurements. These terms characterize the impact of seismic waves on the surrounding environment. Waves create elastic deformations in the environment as a result of which the environment vibrates. Vibration velocity demonstrates the horizontal and vertical movement, which occurs during a unit of time, acceleration demonstrates the speed of the change of this movement. Generally, mm/s or c/s are used as a unit of measure in case of velocity and m/s² in case of acceleration. In order to find velocity and acceleration, amplitude and frequency of vibration have to be measured, i.e. maximum deviation from equilibrium state (normal state) and the number of full vibrations per unit of time. To put this in a more simple way, by considering the vibrations as harmonious and taking only the maximum values into account, the equations of vibration velocity and acceleration can be found by using formulae (1) and (2):

\[
\begin{align*}
V &= A \cdot \omega \\
\alpha &= \frac{V}{\omega} = \frac{A \cdot \omega}{\omega} = A
\end{align*}
\]
\[ v = 2 \pi f A, \]  
(1)

where:  
\( v \) – vibration velocity [mm/s];  
\( f \) – vibration frequency [Hz];  
\( A \) – vibration amplitude [mm]

and

\[ a = 4 \pi^2 f^2 A. \]  
(2)

where:  
\( a \) – vibration acceleration [mm/s^2] [3].

The speed of spreading of seismic waves remains within kilometres per second, which makes it complicated to measure it without special measuring equipment.

V. FACTORS AFFECTING VIBRATION INTENSITY

Parameters affecting vibration velocity of particles caused by seismic waves can be divided into two categories: uncontrollable and controllable. Uncontrollable factors are geological and geomechanical structure of the block to be blasted and its surrounding [3]. Vibration spreads equally in all directions in homogeneous environment, but unfortunately, almost the whole calcareous upper layer of Estonia is mostly full of south-east and north-west directional disturbances. [1]. In addition to the disturbances, shaking of the ground reaching the objects under protection located nearby is also affected by the thickness of the soil layer covering mineral resources having the effect of decreasing the speed and frequency of a seismic wave due to larger elasticity modulus than the rock mass.

Controllable parameters determining the seismic effect are the quantity of explosive to be blasted at a time, distance of the area to be blasted from the object under protection, specific charge of an explosive, type of an explosive and geometric parameters of the blasting operations, such as hole diameter, height of the bench, distance of the first row holes from the smallest resistance line, length of the stem [3].

VI. APPLICABLE EXPLOSIVES

As to the dimensions affecting the performance of an explosive, the blasting result as well as impact on the surrounding environment, depend mostly on two parameters: detonation speed and amount of the explosive gases that emerge. Explosives with higher detonation speed cause a larger seismic effect. Studies have demonstrated that emulsion explosive causes two times more intensive vibration than ANFO [3]. ANFO’s detonation speed is 2.500 – 3.500 m/s, emulsion explosive Senate Powerfrag 3,500 – 5,300 m/s [4].

Specific Charge of an Explosive and Geometric Parameters of the Block to be Blasted

Specific charge of an explosive is the quantity of an explosive needed for crushing a volume unit of a rock. The specific charge of an explosive is in the Aru-Lõuna quarry generally 0.45 – 0.6 kg/m^3.

Together with the wish to reduce vibration velocity of the particles, a desire to reduce the specific charge of an explosive may emerge. In practice, such logic does not correspond to reality - by decreasing only the quantity of an explosive and not changing the geometric dimensions of the holes, a situation is created where the pressure and radial tensile stress, reflecting from the free surface, created upon detonation of the explosive cannot make enough fissures in the rock any more, capacity of explosive gases to enlarge the fissures and push mass is inhibited and the energy unused for effective work is added as an amplifying force to the creation of seismic waves [2].

The rock mass has tectonic fissures, which may have been stretched quite large due to the previous blasting, which occurred nearby, and thus the work as a drilling jumbo operator requires good eyes and intuition. When drilling holes in such situation in regular distance from the smallest resistance line, there is a risk of hitting hollow spaces and heavily weakened rock mass, which additionally to complexity of loading causes very likely the so-called “spattering blasting”, i.e. pieces of rock coming horizontally out from the vertical free surface (bench wall) of the block to be blasted. Although the hazard zone is marked and guard is exhibited before each blasting, it is a very dangerous situation.

In order to avoid this, the operator drills the holes somewhat further than usual from the edge of the bench, at the same time looking for pillars not weakened by fissures. By doing so, the result is holes of quality and usual charge mass. In addition to the decreased specific charge, the destruction power of the first row decreases significantly too. The Aru-Lõuna quarry is very sensitive to the above-described situation. The bottom layer of the quarry is in addition to softness also slippery. Due to good sliding qualities, there are occasions when as a result of blasting, a part of the mass between the first row and vertical free surface move vertically by preserving its initial height and creating tremendous monuments.

VII. RESULTS

The aim of this study was to find out what is the relation between registering the blasting parameters and seismic events, if there is any relation at all. One single and conclusive answer was not reached, and additional studies are needed to be conducted for clarifying the situation.

Differences of the magnitudes of the seismic events under observation are small. Based on the logic that the larger the seismic event the more stations register it, the localization of man-made events of magnitudes 0.7 – 1.1 at the bordering areas of the monitoring network can be considered to be very good. Ten events have been localized with the smaller error than 10 km, eight of them with a standard error smaller than 5 km. The actual epicentres were mostly located in the D sector of the quarry (Fig. 4.) but contrary to the expectations, the qualities, quantities, duration of the delay and specific charge of the explosive used did not differ between blasts that were seismically detected and blasts that were not.

VIII. SUMMARY

Today, co-operation between the companies conducting blasting operations and seismologists is not directly regulated and it is only based on the principle of voluntariness. Although the work of seismic stations is not affected by the exchange of information, it facilitates the work of the people processing seismograms by increasing certainty upon localization and enabling to distinguish between seismic events caused by regular mining or military activity and natural earthquakes or events caused by other human activity.
For example, by doing this, it is possible to detect illegal application of explosives. Sending the times when blasting operations are carried out causes only a minimal amount of additional work for seismologists. Operative feedback makes it possible for the blaster to reduce the need for periodical local measuring as it helps to assess the scope of the impact of the ground vibration caused by seismic waves on the nearby objects and the scope of the risk caused to them. At the same time, it is possible to compare and even improve the quality of blasting as larger seismic effect of the blasting with approximate charge parameters, without taking geological anomalies into account, is caused by the efficiency of the explosion energy – in other words, the ratio of effective work to potential energy is (usually less than 10%). Potential energy of an explosive is maximum work that explosive gases can perform upon the transfer of the whole internal energy to mechanical work. [6].

Potential reasons for registering and not registering the seismic events from the position of the blaster were dealt with in this study. Unfortunately, the lower limit of seismic registration is set high because of the large noise background due to the relatively unfavourable geological conditions of Estonian stations (loose sediments and porous bedrock). Blasting operations in the Aru-Lõuna quarry have been dated quite accurately, and therefore it should be possible to find on seismograms manually seismic wave oscillation caused by blasting for several such events that were not detected by the automatic registration system with the given detection tool parameters. It cannot be excluded that single registrations are the result of concurrence of greater blasting and favourable (causing less seismic noise) weather conditions. If it should appear that today monitoring stations do not detect automatically the majority blasting operations just because of being scantily under the threshold, it may be reasonable to take actions in order to adjust the lower limit.

ACKNOWLEDGEMENTS

This work is linked to the research projects „ETF9018 – Mine collapses in NE Estonia – detection, identification and causes” and „AR12007 - Sustainable and environmentally acceptable Oil shale mining”. Publication of this paper has been supported by European Social Fund (project “Doctoral School of Energy and Geotechnology II”). Many thanks to companies that provide data for this study: Lõhketööd OÜ and Kunda Nordic Tsement AS.

REFERENCES