Methodology of evaluation the effects of seismic blasting in quarries

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Abstract: *Blasting has positive effects and negative impacts causing damage to surrounding civil objects. The intensity of seismic waves' vibrations is proportional to the weight of the applied explosive. If the vibrations are sufficient in energy, surrounding buildings can be damaged or destroyed. Evaluating the negative effects of the blasting operations and quantification of the seismic safety is nowadays very actual and a challenging problem. The article presents the results of the analysis as well as an evaluation method of seismic safety of the objects during blasting work held by the seismic waves' attenuation law in Dubina quarry. The results of the evaluation of seismic effects of blasting verified in a Dubina quarry are the methodological base for evaluation of the effects of seismic blasting in all quarries in Slovakia.*

Keywords: *seismic blasting*

1. Introduction

The rock blast seismics is part of seismic engineering. In practice the seismics of rock blasts is predominantly focused on solution of the following issues.

- measurement and evaluation of particular vibration effects rising from a defined source on a given receptor,
- prognostics of effects of a potential source on a given receptor,
- prediction of effects of a defined source on a potential receptor.

In practice all tasks of rock blast seismics are given due to combination of three basic issues. Due to the previous statement it follows that there exist three components which are predominant for the rock blast seismics:

1. source of vibration,
2. transmitting medium,
3. receptor.

For example, blasting, we examined the quarry Dubina, it is possible to describe the methodology of seismic blasting.

Blasting operations were used exclusively for mining. Recently, they are gaining wider application in other branches of industry, i.e. in building industry, forestry, metallurgy, demolition of buildings, combating natural disasters, etc. Besides their positive effects they also have negative ones, that depend on a distance, which can endanger the objects situated close enough to the blasting. The bigger the explosive load the higher the intensity of seismic waves propagating in rock environment and gradually excite individual elements of the rock environment. If the intensity of vibration is high enough, it can lead to the damage of a construction and eventually to its destruction. Nowadays identifications of these negative effects and seismic safety assessment are very actual problems. An economical solution that, on one hand would prevent damage of object and on the other hand would assure the highest possible efficiency of the blasting, should be found.

The criterion of the seismic safety is the relative deformation and the measure is velocity of vibration [1].

For workings which need to have long operational life the condition for seismic safety (i.e. allowable velocity of vibrations v_p) can be expressed in dependence on the velocity of longitudinal waves in the rock massive c_p [1]:

$$v_\mathbf{p} = 0{,}0001 c_p \ \ \mathrm{m \cdot s^{-1}}, \qquad (1)$$

If this statement is valid then it mainly relates to the field of propagation of seismic waves.
The example of previous theorems is the relation for determination of velocity of vibration (2) and following relation for determination of allowable velocity of vibration (4) [2]:

$$v = KL_R^{-2,21 L_R^{-0,05}} \text{ mm·s}^{-1}, \tag{2}$$

where “K” is a coefficient which determines the properties of the desintegrated rock mass, properties of rocks in the field of basics of building and conditions of rock blast and L_R is reduced distance, $L_R = L/Q^n$, where n is an exponent expressing condition of seismic waves [2].
By the substitution $v = v_p$ the condition of seismic safety of blasting operations is defined as follow:

$$v_{\mathbf{p}} = KL_{R\mathbf{ep}}^{-2,21 L_{R\mathbf{ep}}^{-0,05}} \text{ mm·s}^{-1}, \tag{3}$$

where L_{Rep} is reduced equivalent allowable distance and v_p is an allowable velocity of vibration. L_{Rep} value contains (seismically safe) explosive load Q_p. Relations (2) and (3) come from Sadovsky principle which reflects the similarity rule. This criterion of similarity was the first time used for reduced load $Q_R = Q^m/L$ or reduced distance $L_R = L/Q^n$, where m = 1/3 and n = 1,15 to 1,6 are an exponents expressing conditions for rock blast and attenuation of seismic waves [2].
An empirical formula, so-called Langefors or also Koch [3] is used for determining the maximum values of a velocity of vibration in a distant zone. This formula that is used mainly for evaluating the seismic effect of blasting operations in opencast quarries is often given in the form $v_{max} = K \cdot Q^m \cdot L^{-n}$; where v_{max} – the maximum velocity of vibration, mm·s^{-1}; *Q* – the weight of the charge, kg; *L* – the distance from the source, m; and *K, m*, and *n* are empirical parameters [4, 5].
Some of recent publications prove that the exponent m = 1/3 is valid only for concentrated loads. For cylindrical loads m = 0,5 can be used [6]. US Bureau of Mines recommends analogical relation [7]:

$$v = K(L/Q^{0,5})^{-n} \text{ mm·s}^{-1}. \tag{4}$$

Relation (4) is called by some authors the law of attenuation of seismic waves [3 - 7]. It is applicable for mathematical and statistical processing of the v value measurement results of the v values. K and n values reflect particular conditions of transmitting environment and disintegration in certain range of L_R values for which they were determined. They can be used only for analogical conditions, i.e. equivalent transmitting environment and equal conditions of disintegration – they do not have general validity [4 - 6].

2. Experimental Research

The law of seismic wave attenuation was used for assessment of technical seismicity effects of the bench blasting on the construction of transmitter nearby excavation zone of Dubina quarry. The quarry is located approximately 8 km southward from Poprad city in the eastern part of Slovakia. The task was to assess effects of artificially activated seismicity on the transmitter by bench blasting and to design the plan for following mining works in such way that damage of the transmitter does not occur [8]. Transmitter is located approximately 40 m from the excavation zone boundary of Dubina quarry. Dubina quarry is situated in the rock environment of melaphyre porphyrite which has grey, grayish-green, pink and light brown colour. Rock environment is significantly faulted by the system of parallel structures [9].
Digital fourchannel seismograph UVS 1504 and seismodetectors by Swedish company Nitro Consult (Figure 1) were used for measurement of seismic effects.

Fig. 1. Installation of seismograph and seismic detectors before rock blast on the steel construction of transmitter

There were drilled 21 boreholes in total on the bench No. 19 (CO 19) (Table 1). Total explosive load during CO 19 was 2 092 kg.
The construction of the load in particular boreholes is shown in the Table 1.

Tab. 1. Construction of loads in boreholes during CO 19

Boreholes number	DAP [kg]	POLONIT [kg]	DANUBIT [kg]	Total explosive load kg/ borehole
1-13	50	14	40	104
14	50	10	40	100
15	50	-	45	95
16-17	50	-	42,5	92,5
18-21	50	-	40	90

There were drilled 20 in total on bench No. 20 (CO 20) (Table 2). Total explosive load during CO 20 was 1 980 kg. The construction of the load in particular boreholes is shown in the Table 2.

Tab. 2. Construction of loads in boreholes during CO 20

Boreholes number	DAP [kg]	POLONIT [kg]	DANUBIT [kg]	Total explosive load kg/ borehole
1-20	50	24	25	99

3. Results and discusion

Values measured at basal plate and at the construction of transmitter during bench blasting No. 19 are shown in the Table 3. Values measured at basal plate and at the construction of transmitter during bench blasting No. 20 are shown in the Table 4. Position of the transmitter and CO 19 & CO 20 is shown in Figure 2.

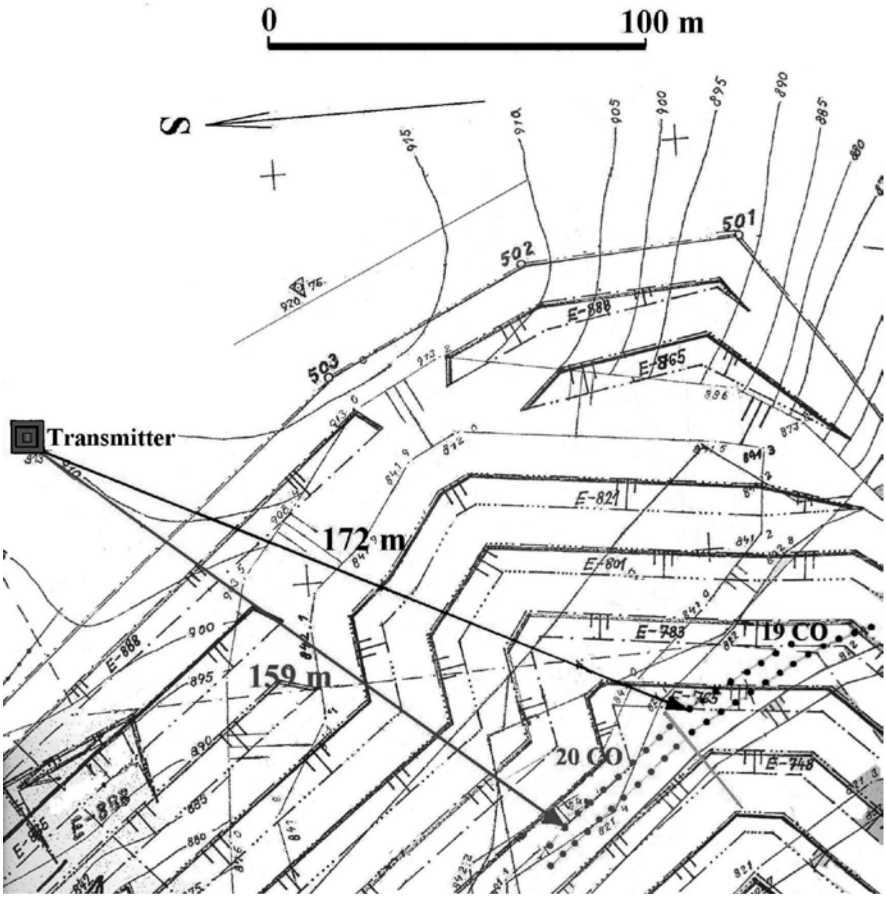

Fig. 2. Position of CO 19 and CO 20 with respect to the transmitter with distances marked in Dubina quarry

According to long-term experiences obtained during measuring of seismic effects of bench blasting, it was determined that even in the case of measuring of the same rock blast in the same standpoint by a couple of identical equipment sets it is possible to obtain three times bigger and also higher variable of measured speed characteristics. Therefore the measurement, analysis and assessment of seismic effects require mathematical and -statistical approach [10 - 12]. The theory and experiments in several quarries showed that velocity of vibration is well governed by semi-empirical law of seismic waves` attenuation which is given by relation:

$$v = K\left(\frac{L}{Q^{0,5}}\right)^{-n} = K\left(\frac{Q^{0,5}}{L}\right)^{n} \text{ mm}\cdot\text{s}^{-1}, \tag{5}$$

where v is maximum velocity of vibration (maximum component of velocity of vibration) activated by rock blast, $mm\cdot s^{-1}$; $L/Q^{0,5}$ is reduced distance, $m\cdot kg^{-0,5}$; L is the shortest distance source of vibration from receptor, m; Q is weight of explosive charge of time stage, kg; K is coefficient dependent on conditions of rock blast, properties of transmission of rock environment, type of explosion and so on and n is index of seismic waves` attenuation.

There is a theoretical relation of the effect and causality between v and L_R (resp. Q_R) variables. Because of high variability of recorded values of **v** between different rock blasts, and at different locations the velocity of vibration is considered as dependent variable and the reduced distance $L_R = (L/Q^{0,5})$ as independent variable. Both values are stochastically jointed (not functionally). Therefore, the law of seismic waves` attenuation of investigated area is studied by statistical methods based on trial rock blasts.
By taking a logarithm of relation (5):

$$\log v = \log K - n \log\left(\frac{L}{Q^{0,5}}\right), \qquad (6)$$

we have relation (6) which is represented by line inclined by an angle β logaritmical scale.
Based on the collected data graphic relation of maximum components of velocity of vibration on reduced distance during bench blasting 19 & 20 CO was created. Graph in Figure 3 shows, so called principles of seismic waves attenuation for Dubina quarry. From the seismic waves` attenuation law (5) it is possible to determine the amount of explosive charge and to determine (preliminarily) expected velocity of vibration generated at protected object by rock blast for minimum distance of rock blast from object under consideration L.

Tab. 3. Measured velocity values during CO 19

standpoint	X [mm·s^{-1}]	Y [mm·s^{-1}]	Z [mm·s^{-1}]	Z_k [mm·s^{-1}]
steel construction of the transmitter	3	3,35	6,95	25

Tab. 4. Measured speed values during CO 20

standpoint	X [mm·s^{-1}]	Y [mm·s^{-1}]	Z [mm·s^{-1}]	Z_k [mm·s^{-1}]
steel construction of the transmitter	8,35	5,75	9,65	8,3

Z_k record from the receiver placed at the construction of transmitter post

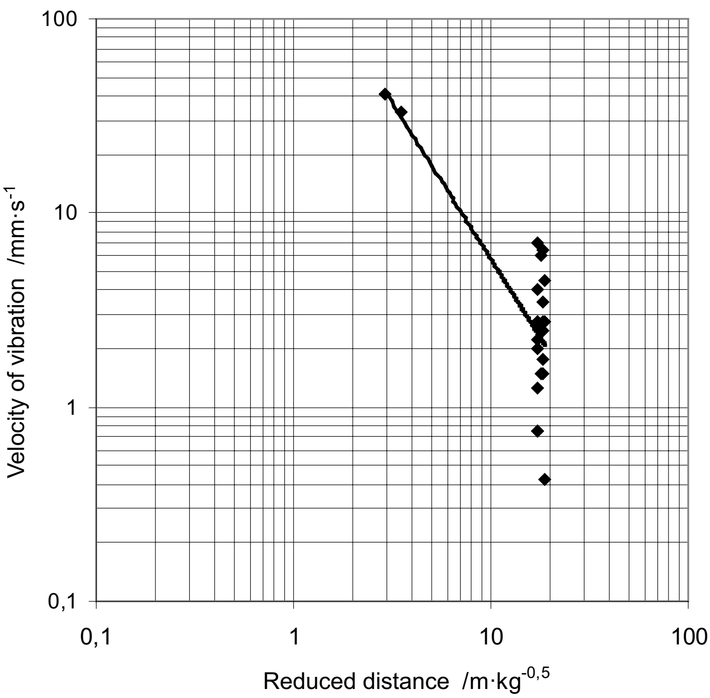

Fig. 3. Graphical dependence of maximum component of velocity of vibration on reduced distance for bench blastings in Dubina quarry-the seismic waves` attenuation law

4. Conclusion

The article presents results of experimental measurements of the maximum amplitudes velocity of vibration caused by the blasting work in the opencast quarries used in Slovakia. The geological situation in individual locations are different. Seismic wave attenuation law, which was used for measurements over longer distances and also in the near zone is used for the evaluation of seismic safety of blasting.
From the researches which were done at faculty BERG of Technical University in Kosice in recent years it unambiguously resulted that for the assessment of seismic safety of bench blasting of bigger range it is required to determine the seismic waves` attenuation law for investigated area. The amount of necessary data for mathematic-statistical determination of the seismic waves attenuation law is relatively high. Therefore it was require evaluate a number of measurements of several standpoints to obtain required statistical set for determination of the seismic waves` attenuation law. This method of evaluation of seismic effects in quarries results in new point of view of a given problematic and enables acquisition of further practical knowledge in the area of assessment in technical seismicity.

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