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EXAMPLES OF LAW OF SEISMIC WAVE ATTENUATION

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The article summarizes experimental seismological measurements of vibration effects of blasting operations. During tunnel excavation can watch a variety of effects on the near or distant surroundings of the building. One of the most discussed are the effects of vibration, while the most important vibrations are caused when part of the excavation technology also use blasting. In this paper, we focus on the design summary of results from experimental seismological measurements, and the values of the maximum amplitude of vibration, which are measured at small distances from the source of vibration. For comparison also gives the results of experimental measurements of vibration induced at larger distances, or quarries.

Key words: blasting operation, vibration velocity, seismic wave attenuation

INTRODUCTION

In the course of tunnel driving we can observe a number of various effects on less or more distant surroundings of the construction work under construction. Vibrations are one of the most discussed effects; the most significant vibrations are induced by use of blasting operations. In the paper we will focus on giving a summary of the results of experimental seismological measurements, i.e. on the maximum amplitudes of vibration that are measured at small distances from a source of vibrations (called also near zone). Also the results of experimental measurements of vibration generated at greater distances, or in the vicinity of quarries, are given to compare.

The values of the maximum sizes of the amplitudes of vibration induced on blasting of explosives are influenced by many factors ([1-3]). In spite of that, relatively simple formulas are used for estimating these sizes today. Most of them can be written in the formal form as the formula v = f (Q, R), where *v* is the maximum particle velocity, Q is the weight of the explosives (usually at one time stage) and R is the distance between the source of vibrations and the place under consideration. This general formula can be found in various forms in the literature. A more detailed list of these formulas from various localities can be found, for example, in the publications by [4] or [5].

A number of examples from the Czech and Slovak Republics, subsequently plotted on graphs, make it possible to draw up summary information in the form of one of commonly used formulas. A graph uses a so-called reduced distance, which makes it possible to consider the weight of the explosive used. Sensors during measurements were placed on rock massif, typical frequency range of seismic channel was 2 – 200 Hz and sampling frequency of digital signal was 250 Hz usually.

FORMULAS USED FOR OPENCAST QUARRIES

The explosion of a charge of explosives generates a short but intensive pulse. The range of the maximum amplitudes of motion induced on the blasting of a charge is 1 to 200 μm (i.e. approx. 0,2 up to 50 $mm\cdot s^{-1}$ or 0,02 up to 1 $m\cdot s^{-2}$). Its spectrum is continuous and contains frequencies from lower values up to very high values – usually of 1 up to 300 Hz. These values can change insignificantly in dependence on the literary source used. Generally, it is necessary to add that the type and properties of the rocks to be blasted, the explosive parameters and the technology of the blasting operations to be carried out have to be taken into account for determining the sizes of the maximum amplitudes of vibration [6].

An empirical formula, so-called Langefors or also Koch (e.g. [7, 4]) is used for determining the maximum values of a particle velocity 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 particle velocity /$mm\cdot s^{-1}$;
Q – the weight of the charge /kg;
l – the distance from the source /m and K, m, and n are empirical parameters.

Graphs are plotted either as the dependence of the maximum velocity of vibration v_{max} on the distance or on the so-called reduced distance L_R, which is the ratio

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of the distance l to the square root of the weight of the charge blasted Q ($L_R = l/\sqrt{Q}$). If we base on the Czech ČSN 73 0040 standard or the Slovak STN 73 0036 standard, then the values of the empirical constants in the exponents are considered in sizes m = 0,5 and n = 1. Therefore, the mentioned formula changes to the form

$$v_{max} = K\frac{\sqrt{Q}}{l}.$$

This formula, called the law of seismic wave attenuation, can be defined very well; however, it can have a very low correlation for complicated geological conditions (e.g. [4, 8, 9]). Not only the record of a vibration effect as a whole but also individual parts of the record corresponding to individual time stages (if individual stages can be separated) can be used for drawing up the formula.

The mentioned standards define informative values of the coefficient *K* for bedrock or a base of semi-rocks and other rocks except for rocks in a water-bearing environment in dependence on the distance from the blasting point (Table 1). This informative table is used for estimating the maximum amplitude of a velocity of vibration using the last formula unless more detail information on the rock environment is available [10].

These values from Table 1 are suitable especially for blasting operations of a large extent in opencast quarries and for distances in hundreds of meters from a blasting point.

Table 1 **Information values of the coefficient K/kg$^{-1/2}$·m^2·s^{-1} (according to [11-12])**

Distance / m	The bedrock of rock – medium to very law density of disturbances	Other rocks in the aquifer environment
10	350	250
50	250	150
200	150	120
500 and more	120	100

The same formula is also used for evaluating in tunnels and quarries, both for large and small distances, in the following text. The methodology has been selected for processing the whole data set where the maximum values of the amplitudes of a particle velocity at individual components (vertical, horizontal radial, and horizontal transversal) are interpreted and subsequently the spatial component is calculated (according to the formula: $v = (v_x^2 + v_y^2 + v_z^2)^{0,5}$. The coefficients K are subsequently calculated from this value and the appropriate dependences are drawn up.

EXAMPLES OF THE RESULTS OF MEASUREMENT AT GREATER DISTANCES FROM A SOURCE OF VIBRATION

The example of results that were obtained from the long-term monitoring of seismic effects of blasting operations comes from driving the tunnel of Klimkovice near Ostrava which is a part of Motorway D47 (e.g. [13]). The tunnel itself is 1,080 m long. It passes through the land elevation between Klimkovice and a part of Hýlov.

Driving the tunnel was carried out in the bedrock of broken carbon; a typical rock massif was a combination of pelitic claystones and siltstones with greywackes and subgraywackes in the form of flysch series of strata. It is this rhythmic flysch stratification of clay and sandstone strata what is typical to the Ostrava area. The angle of strata varied slightly (60 - 70 °) in the course of work and was interwoven with frequent discontinuities, mostly perpendicular to stratification. Further, five faulted bands were indicated, passing mostly obliquely to the tunnel axis. The underground water is bound especially to joints and tectonic disturbances. The environment of the massif is generally variable and is characterized as less permeable. Verified water inflows in driving mostly did not exceed 1-2 l·s^{-1}.

The correlation of the maximum amplitudes of the velocity of vibration with a reduced distance was drawn up from selected data (Figure 1). This relation is not well defined because the range of reduced distances is very small. We define two values of the transfer constant K (= v_{max} · l/√Q) from this relation, for the smallest (K_1) and the greatest (K_2) reduced distance with the spatial maximum amplitude of the particle velocity at the given reduced distance:

$$K_1 = 88{,}19\ K_2 = 97{,}18\ \text{kg}^{-1/2}\cdot\text{m}^2\cdot\text{s}^{-1}.$$

The territory is a part of the Križňany nappe, but it partially differs lithologically from typical profiles of this tectonic unit. It is assumed that this may be a shallow sedimentation area in which Mesozoic carbonates of Humenné hills have sedimented. The deep water sedimentation of limestones continues down to the Lower Cretaceous [14].

The experimental measurement of vibrations took place in the vicinity of a cave that is situated in the area of the quarry of Brekov (Figure 2). During this measurement, a small quantity of data was obtained (four reduced distances only); the relation obtained is rela-

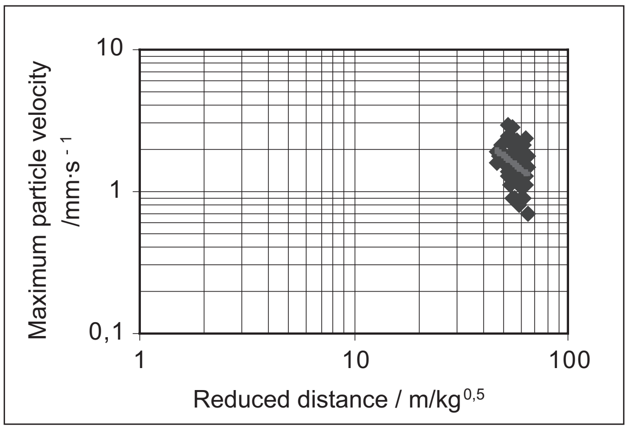

Figure 1 Graphical dependence of the maximum values of the particle velocities on the reduced distance in experimental measurement at the tunnel of Klimkovice – the law of seismic wave attenuation

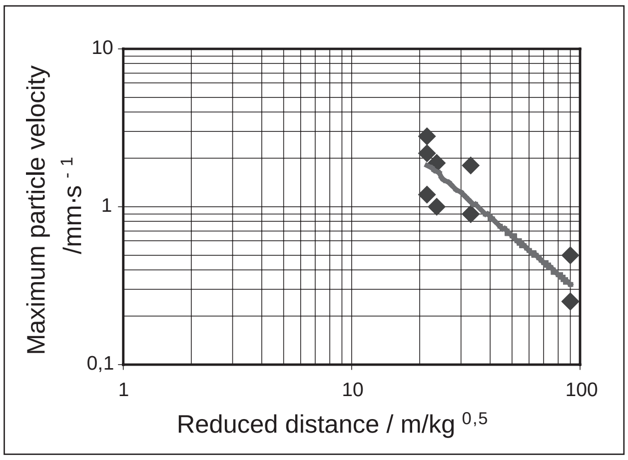

Figure 2 Graphical dependence of the maximum values of the particle velocities ion on the reduced distances during experimental measurement at the quarry of Brekov – the law of seismic wave attenuation

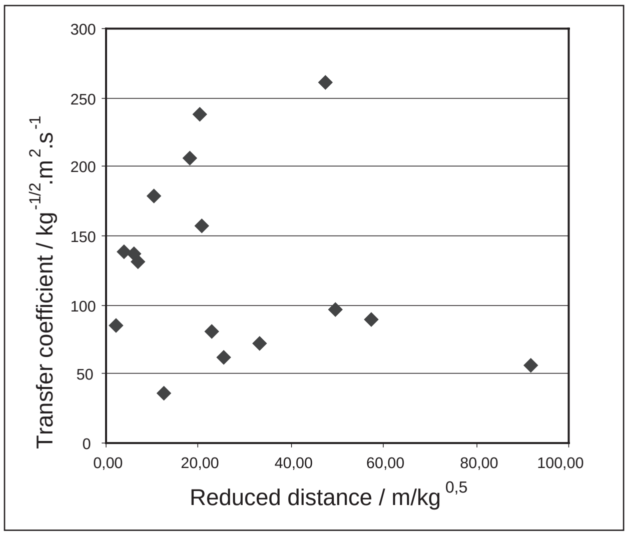

Figure 3 Dependence of the transfer coefficient K on the reduced distance for the data from the aforementioned examples

tively well defined. The obtained end transfer constants reach the values:

$$K_1 = 72{,}75 \quad K_2 = 56{,}12\ kg^{-1/2} \cdot m^2 \cdot s^{-1}.$$

CONCLUSIONS

The geological situation in individual localities was different. The so-called law of seismic wave attenuation that was used for both measuring at greater distances and also in the near zone is used for assessment. The dependences obtained are statistically significant, freer dependences are usually reached for small values of distances (or reduced distances as the case may be). The fact that quasi-homogenous geological units in which the law of seismic wave attenuation for small distances would be defined have to be defined with a smaller variability of the parameters to be assessed results from this. Two values of the transfer constant K (= $v_{max} \cdot l/\sqrt{Q}$) for each case presented were calculated, for the smallest (K_1) and the greatest (K_2) reduced distances (with the maximum amplitude of the velocity of vibration at the given reduced distance) (Table 2). This graph (Figure 3) supports again the aforementioned knowledge that for greater distances we obtain a relatively homogenous set of coefficients K; however, this dependence is not defined for reduced distances under 40 $m \cdot kg^{-0,5}$. This is connected, among others, also with use of data from localities with various geological structures.

Table 2 **Summary table of the end values of the coefficient K (K_1 and K_2) for all the localities measured**

	Klimkovice	Brekov	Bôrik	Kučín
K_1	88,19	72,75	237,68	178,99
K_2	97,18	56,12	261,54	61,82
L / m	71,9	72,3	115	62,1
v_{max}/mm·s^{-1}	1,9	2,21	11,34	17,05
	Banská Bystrica	Olbramovice	Tomice	Tomice II
K_1	130,74	85,47	137,62	137,91
K_2	35,69	206,27	157,03	80,06
L / m	12	6,5	16	8,5
v_{max}/mm·s^{-1}	19,26	42,31	23,09	35,55

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Note: The responsible translator for English language is the lecturer from Institute of Geonics, Ostrava, Czech Republic