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GROUND VIBRATIONS FROM ROCK BLASTING

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ABSTRACT

Construction of new underground infrastructures such as tunnels for roads and railways beneath populated areas and cities is associated with many restrictions. Ground vibrations due to rock blasting are one of the important aspects that must be considered and often it is necessary to show that the ground vibrations due to a project will not damage nearby structures in order to receive needed permissions for such projects. While it is possible to control the level of vibrations by choosing the right techniques the economical aspects of the project usually requires as high maximum delay weight as possible. Therefore it is desirable to be able to make good predictions on the maximum allowed charges in early stages of the project. In this paper ground vibration measurements from an infrastructure project in Sweden have been compared to predictions based on empirical methods and theories for wave propagation in hard rocks.

Keywords: Ground vibration, Rock blasting

INTRODUCTION

Norra Länken, the Northern Link, is about 5 km City highway tunnel project between Karlberg and Värtan in Stockholm, Sweden that is planned to come into service as of year 2015 at an estimated cost of about 1.2 billion EURO, (Vägverket, 2009). Most parts of the Northern Link consist of underground rock tunnels that partly go under buildings and facilities with vibration sensitive activities and instruments in them. The most sensitive part is under the Albanova University Centre which is part of the Royal Institute of Technology and the Stockholm University. The location of Albanova University Centre is shown in Figure 1 where advanced research work is carried out using the latest equipment in laser and nanotechnology.

From the point of view of economy it is desirable to use as high as possible charge weight per delay, Q, for tunnel blasting. On the other hand the highest possible Q is limited by the maximum permitted vibration level with respect to nearby buildings and their occupants. Therefore an essential part of the planning works for tunnel blasting is assessing safe levels of ground vibrations in order to avoid damage to buildings and their occupants.

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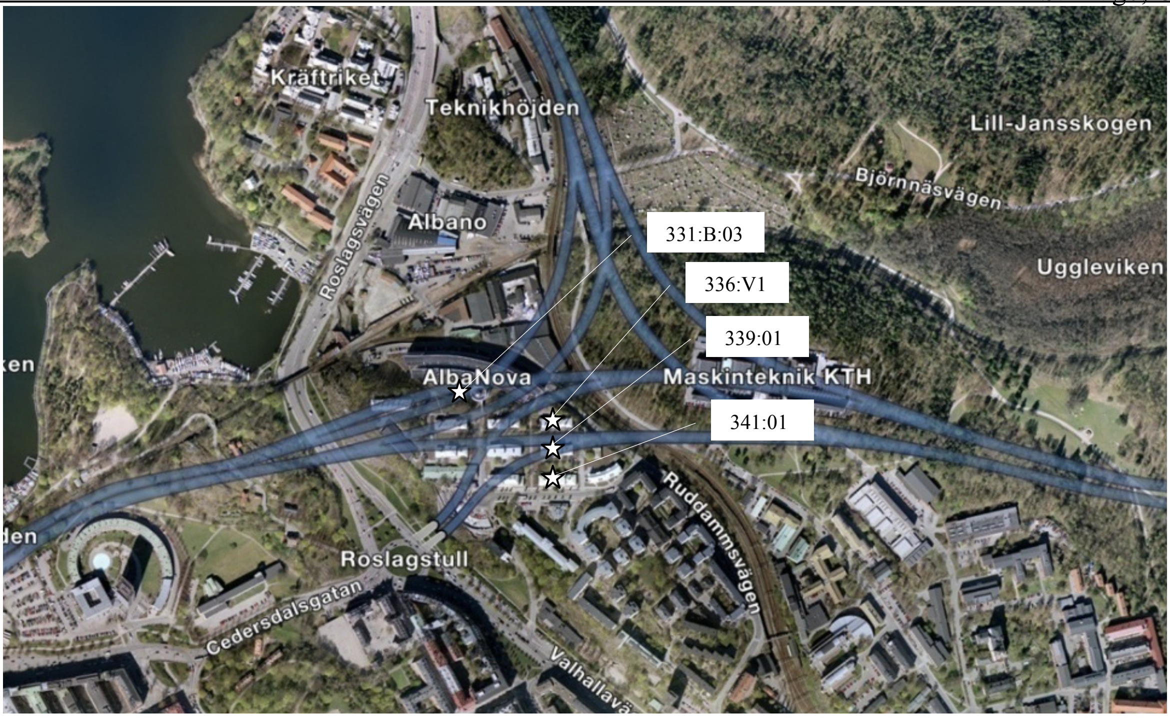

Figure 1. Satellite picture over Albanova University Centre showing the Northern Link, (Vägverket, 2008). The measurement points that have been used in this paper are shown by stars in the figure.

In case of underground rock blasting body waves seem to be more predominant unlike earthquakes where surface waves are usually predominant at large distances from the epicenter. Approximately one-dimensional conditions can be assumed at the wave front when the distance to the blast hole is large compared to the borehole diameter. Therefore the radial component of vibrations, v_R, is more significant than the two tangential components. The radial strain, ε, is shown to be related to the particle velocity, v_R by Equation 1.

$$\varepsilon = -\frac{v_R}{c} \tag{1}$$

where c is the stress wave propagation velocity in the material.

Thus, strain increases with particle velocity and therefore, most ground vibration damage criteria are expressed in terms of maximum permitted peak particle velocity (PPV).

For about two decades the Swedish standard SS 460 48 66, (SIS, 1991) has been used to determine buildings' permitted vibration levels due to construction blasting. In fact the permitted vibration levels given in this way defines the contractor's responsibility in case of damage caused by the blasting. If induced vibrations, according to vibration measurements, are higher than permitted ones the contractor is responsible, otherwise the project owner has to pay for the damages. Nevertheless many years of experience show that damage on nearby buildings due to rock blasting is normally avoided if ground vibrations are limited in accordance with SS 460 48 66.

The permitted vibration level according to the Swedish standard is determined using Equation 2 based on the ground type, the building's type and material, and distance to the blast location and is presented in terms of the vertical component of the particle velocity.

$$v = v_0 \cdot F_k \cdot F_d \cdot F_t \qquad (2)$$

where v_0 is uncorrected particle velocity in vertical direction that depends on the kind of the ground, F_k is the construction factor that depends on the building type and its material, F_d is distance factor that depends on the type of ground and distance from the blast to the building, and F_t is a factor between 0.75 and 1.0 depending on the type of the blast work. For short term construction blast like tunneling it is chosen as 1.0 while for mines and quarries it is chosen between 0.75 and 1.0 depending on how frequent blasting is carried out.

The permitted vibration levels for equipment inside buildings are normally set using information provided by the manufacturer and usually are given as the highest permitted acceleration within certain frequency intervals.

The other side of the problem assessing the damage risk from construction blasting is prediction of ground vibrations caused by the blasts. In order to make such predictions trial blasting is usually used in big projects where rock blasting is of considerable volume. The results from trial blasting may be even used in the design of countermeasures against excessive blast induced ground vibrations.

Nevertheless it must be kept in mind when assessing potential damage risk on nearby buildings and their occupants that damage caused by blasting cannot be predicted precisely. Although the variables of the blast design can be controlled, there is some variation in the strength of the explosive depending on type of product as well as the actual delay time between the individual explosions that comprise a round. Vibration propagation characteristics of the rock are also subjected to substantial random variation as well as the strength and ductility of nearby buildings.

COMPARISON BETWEEN ESTIMATED AND MEASURED VIBRATIONS

In the following the results from vibration measurement during tunnel blasting for the Northern Link tunnels in Albanova area (se Figure 1) are compared with predicted vibration amplitudes based on trial blasting. The vibration measurements were carried out with Infra Mini logger, equipped with GSM communication, and geophones of type Infra V10 and Infra V12 set to the requirements in the Swedish standard SS 460 48 66. The measured data was automatically transferred to a web portal, NCVIB.com, where it can be accessed by authorized people via internet.

Estimation of blast induced ground vibrations

The variation of maximum peak particle velocity with distance from the blast can be defined by Equation 3 in general form. Dimensional analysis indicates that m=0.5 for cylindrical charges and B can vary from -1.4 to -1.8 in practical cases (Department of the Army, 1989). By fitting this equation to the data from trial blasts the two parameters, A and B, have been determined for the Northern Link project (Johansson & Eriksson, 2004). The parameters A and B in Equation 3 are A=1072 and B=-1.54 and the dashed black line in Figure 2 is the best fitted line to the data in logarithmic scale. The standard deviation of $\log_{10}(v_{max})$, S, is 0.19 that is used to draw the other two lines corresponding to the 84 % and 98 % probabilities respectively. The 98% line defines an upper boundary that would not be exceeded with 98 % probability.

$$v_{max} = A\left(\frac{R}{Q^m}\right)^B \quad (3)$$

where Q is the charge weight per delay and R is distance from the blast to the measurement point. A and B are parameters that are determined using trial blasts while m is 0.5 in case of cylindrical charges.

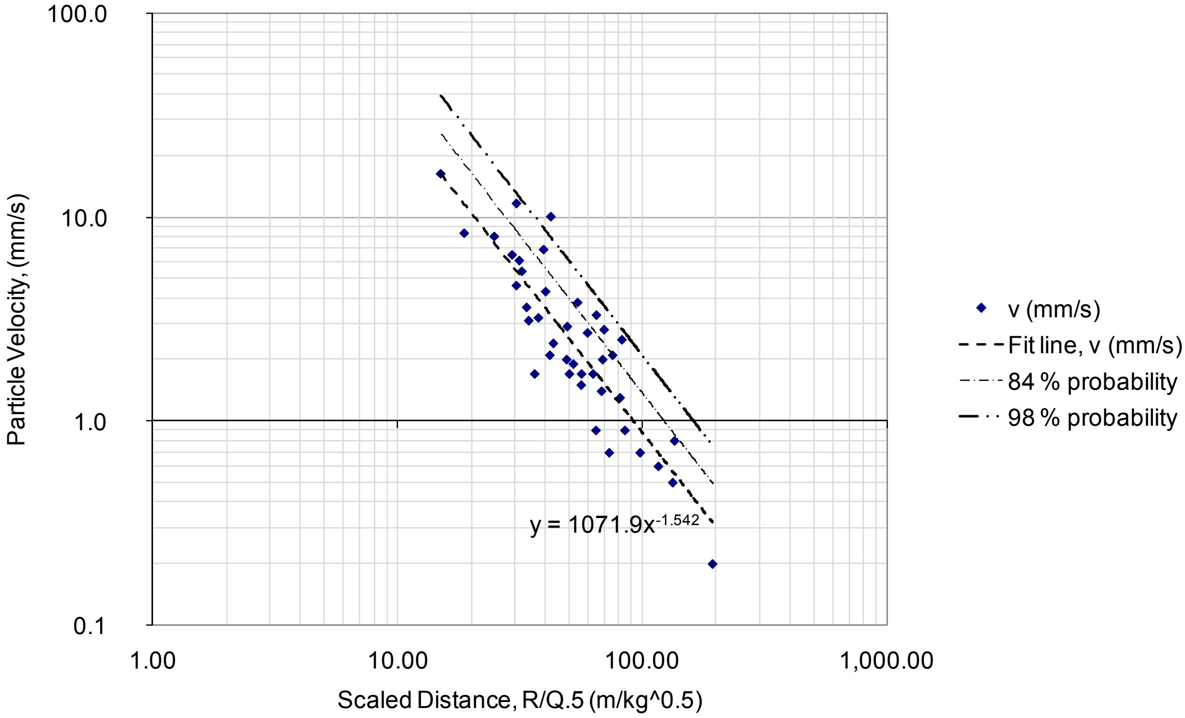

Figure 2. Regression analysis of the trial blast data from Albanova University Centre. The lines correspond to the 50 % (median fit line), 84% and 98% probabilities respectively.

Measurement of ground vibrations from tunnel blasting

Ground vibrations are measured during tunnel blasting in order to monitor the level of vibrations. In general geophones measuring only the vertical component of vibrations have been used while at some measurement points of special interest triaxial geophones or accelerometers have also been used for the measurements.

Four points of measurement have been chosen for the purpose of this study as shown in Figure 1. Three of the geophones mounted in the basement of nearby buildings measure the vertical component of ground vibrations while the fourth one, 331:B:03, which is mounted on a concrete foundation is a triaxial geophone measuring all three components.

Figure 3 shows the measurement results as well as the best line fitted to them, solid black, in logarithmic scale. The other three lines in the figure are given for comparison and correspond to the lines shown in Figure 2.

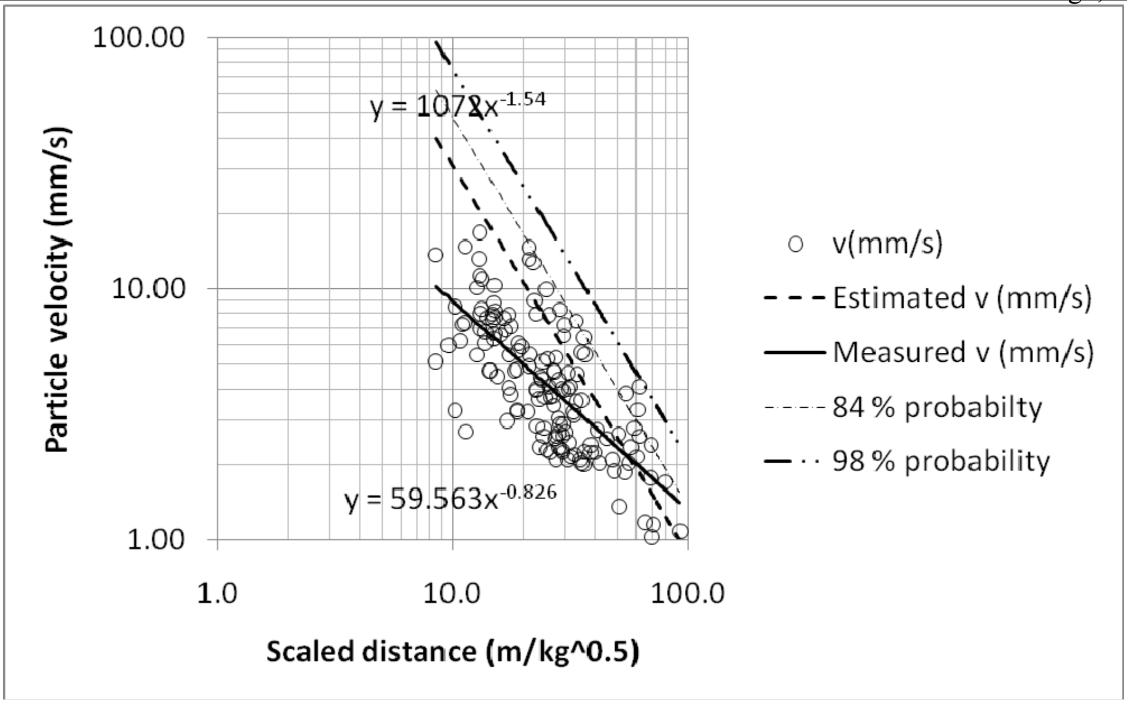

Figure 3. Vertical component of ground vibrations. Circle points in the figure represent measured data during tunnel blasting while the solid line is the best power line fitted to them. The other three lines are corresponding to those shown in Figure 2.

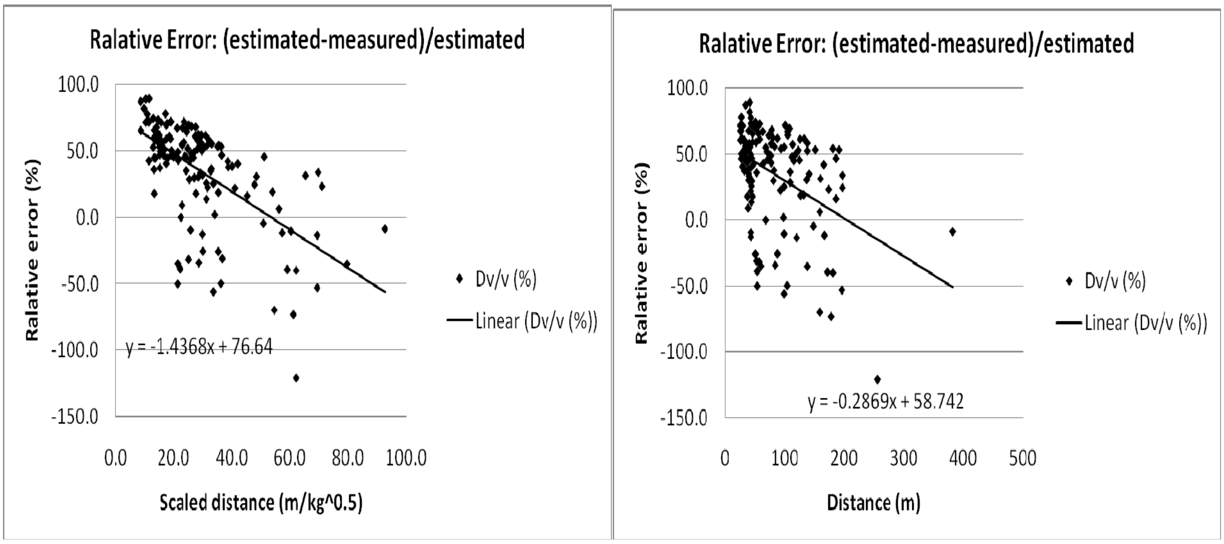

Figure 4. Relative error showing the difference between measured and estimated ground vibrations at different distances both scaled (left) and unscaled (right).

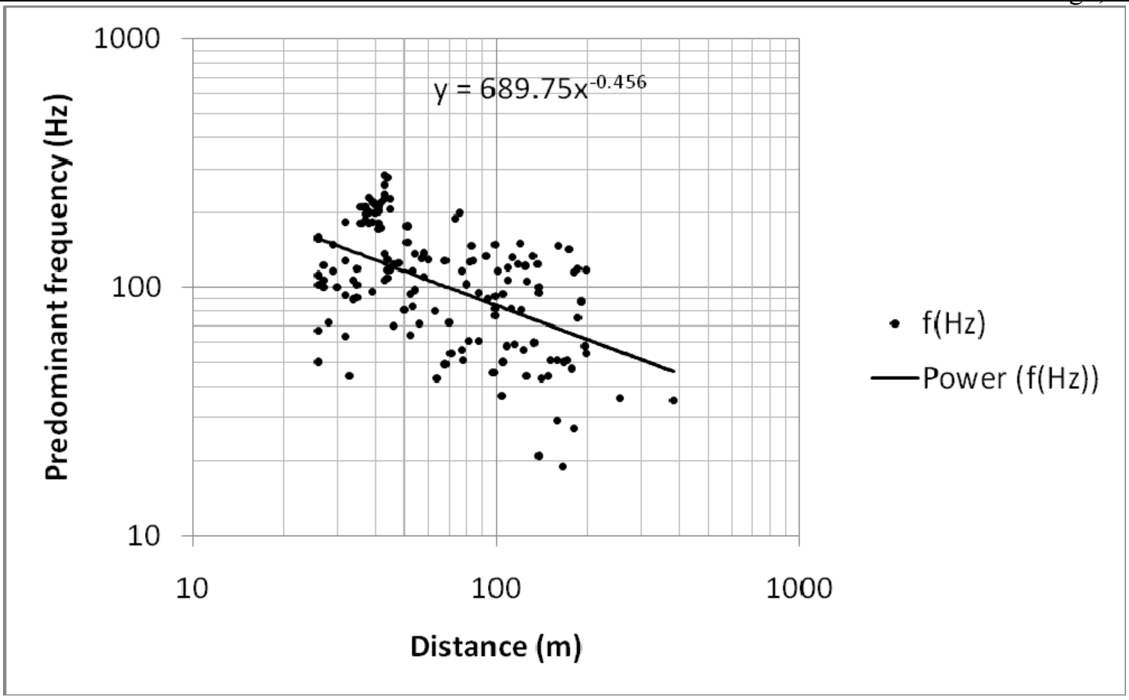

Figure 5. Principal frequency of blast induced ground vibrations at different distances based on vibration measurements during tunnel blasting at four points as shown in Figure 1.

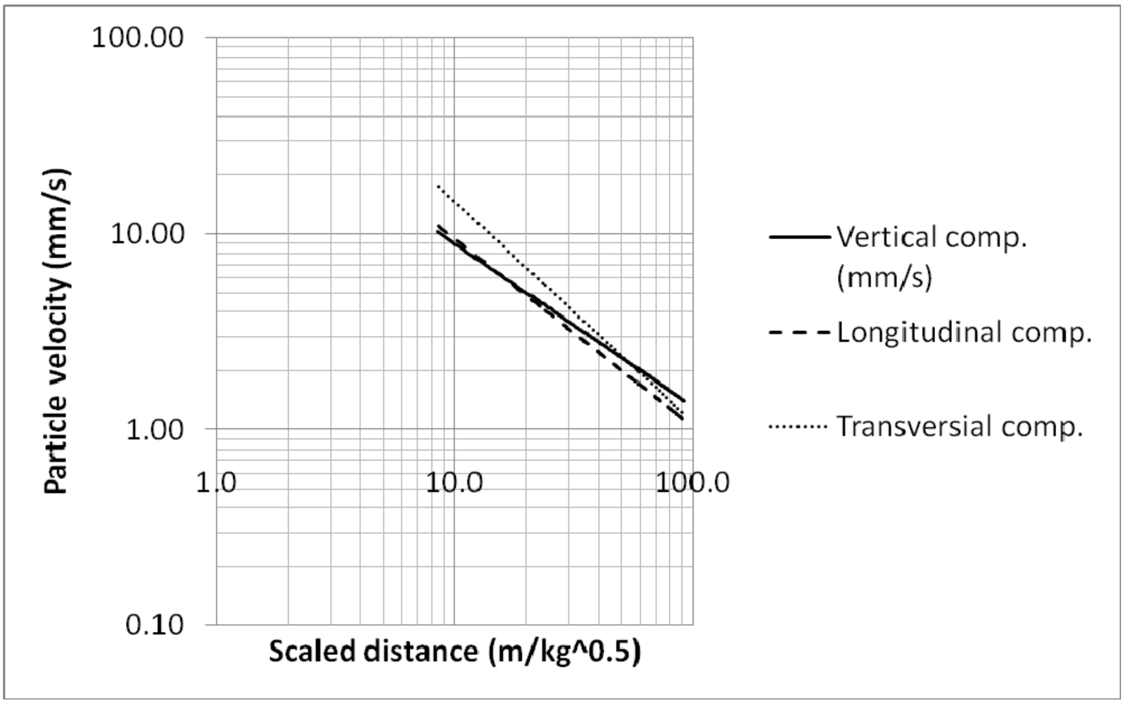

Figure 6. Comparison between the three ground vibration components based on data from measurement point 331:B:03 as shown in Figure 1.

Figure 4 presents the relative error defined as the difference between prediction and measurement divided by the predicted value at Albanova while Figure 5 shows the relationship between the predominant frequency of vibrations and distance to the blasts. In Figure 6 the best fitted lines to all three components of ground vibration at different scaled distances are presented for the measurement data from the triaxial geophone at point 331:B:03.

Due to the fact that blasting is carried out at different locations as tunneling works proceed in different tunnels under Albanova, the direction of the horizontal components of ground vibrations, L and T, varies with respect to the propagation direction of waves. Therefore the regression analysis results in similar lines for the two horizontal components of ground vibrations at point 331:B:03 as shown in Figure 6.

Discussion

As shown in Figure 2 about half the measurement data exceed the solid black line that represents the 50 % probability. Nevertheless this line is used to compare measured ground vibrations from construction blasting at Albanova University Centre with the predicted ones. This comparison is done only for the vertical component of vibrations as the line in Figure 2 is based only on vertical components.

It is seen from Figure 3 that up to a certain distance the prediction line corresponding to 50 % probability, the median fit line that is shown as dashed black line overestimates measured ground vibrations while at large distances the ground vibrations are underestimated by the prediction line. The same information is also shown by Figure 4 that presents the relative error.

According to Figure 4 about 50 % relative error, depending on the distance from the blast, can be expected. This is understandable considering all the limitations of a trial blast. In case of trial blast the charges are in single holes without any free face compared to tunnel blasting with up to 200 holes. The maximum charge weight per delay is also much lower in the trial blasts in order to avoid excessive ground vibrations because all the countermeasures such as vibration isolation of sensitive equipment have not been carried out prior to the trial blasts.

It is also worth mentioning that for the same scaled distance from blast, $R/Q^{0.5}$, the distance to the explosion is shorter for trial blasts. This is due to the fact that the maximum charge weight per delay, Q, of trial blast is less than the corresponding blast during tunnel construction.

On the other hand it is usually close to the buildings that permitted vibration levels are limiting the maximum charge weight per delay during tunnel construction. In the design stage of the project when the trial blasts are carried out it is important that the result of the trial blast does not underestimate the vibration levels from the production blasting at short distances.

In order to define the short distance zone mentioned above in a better way the predominant frequency of the vibrations may be used. As it is seen from Figure 5 the predominant frequency of ground vibrations that decreases with distance from blast is about 150 Hz, on average, at short distance from the blast. This is in line with what is reported in the literature (Dowding, 1984). With an estimated p-wave velocity of 3000-5000 m/s in rock it is possible to calculate the corresponding wave length, λ, to be about 20-33 m at 150 Hz. Referring to the right part of Figure 4 it is seen that the zone inside which measured vibration levels are not underestimated by prediction extends about 200 m from the blast that is equivalent to about 6 times the predominant wave length close to the blast.

Finally it should be mentioned that the two horizontal components of ground vibrations may be as important as the vertical one as it is shown in Figure 6. This is a fact that must be kept in mind when estimating maximum charge weight per delay based on vertical component of ground vibrations.

CONCLUSIONS

Trial blasting is an effective way of predicting ground vibrations due to rock blasting. Even though the maximum charge weight per delay and the total charge weight in the trial blasts are much lower than the actual charge weights used in rock blasting during tunnel construction the ground vibrations are predicted with acceptable accuracy. The experience presented in this paper shows that within about 6λ from the blast the predicted values would not underestimate ground vibrations caused by construction blasting. This is normally acceptable as most risk objects are located inside such a zone. Furthermore vibration measurements during construction are used to avoid excessive ground vibrations.

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