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Selection of site specific vibration equation by using analytic hierarchy process in a quarry

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ABSTRACT

This paper presents a new approach for the selection of the most accurate SSVA (Site Specific Vibration Attenuation) equation for blasting processes in a quarry located near settlements in Istanbul, Turkey. In this context, the SSVA equations obtained from the same study area in the literature were considered in terms of distance between the shot points and buildings and the amount of explosive charge.

In this purpose, 11 different SSVA equations obtained from the study area in the past 12 years, forecasting capabilities according to designated new conditions, using 102 vibration records as test data obtained from the study area was investigated.

In this study, AHP (Analytic Hierarchy Process) was selected as an analysis method in order to determine the most accurate equation among 11 SSAV equations, and the parameters such as year, distance, charge, and r^2 of the equations were used as criteria for AHP.

Finally, the most appropriate equation was selected among the existing ones, and the process of selecting according to different target criteria was presented. Furthermore, it was noted that the forecasting results of the selected equation is more accurate than that formed using the test results.

1. Introduction

Apart from its economical and production benefits in mines and quarries, blasting techniques create many adverse effects, such as environmental problems. First and foremost, the seismic waves produced by blasting causes damage on nearby structures and buildings. Frequency and particle velocity components are the most effective parameters on blast induced damage. Hence, determining the seismic energy distribution is important. This aspect has to be taken into consideration in the course of blast design, particularly with respect to minimizing the environmental issues (Kalayci, 2011).

Over the years and for different aims, many research studies have been carried out on blast induced vibration propagation. Although their main purpose was to isolate environmental issues, additional reasons included scaling the blasting performance and predicting and controlling the structure response (Dowding, 1985; Ambraseys and Hendron, 1968; Siskind et al., 1980; Ghosh and Daemen, 1983). Researchers considered, scaled distance, charge per delay and peak particle velocity data as decisive parameters and used statistical approximations as the analysis technique (Dowding, 1985; Siskind et al., 1980; Ghosh and Daemen, 1983; Gupta et al., 1988; Nicholls et al., 1971).

It is widely known that blast induced ground vibrations cause damage in ratio to their carried energy level. The energy level of vibrations counted with Particle displacement (mm), Particle velocity (mm/s), Particle acceleration (mm/s^2) and wave frequency (Hz) (Dowding, 1985; Ambraseys and Hendron, 1968; Jimeno et al., 1995; Karadoğan, 2008; Faramarzi et al., 2014). A decisive approximation method or a formula has not yet been established because of the complexity of the subject. However, the well accepted empirical PPV attenuation equation is expressed in the form of a power law, as follows in Eq. (1) (Dowding, 1985);

$$PPV = k * \left(\frac{R}{W^{0,5}}\right)^{-\beta} \tag{1}$$

where PPV is peak particle velocity, W is the maximum charge per delay, R is the distance between the monitoring and shot point.

Because of the complexity of the topic, some researchers used different analyses and intelligent systems for evaluating the vibration components and attenuations (Kahndelwal and Shing, 2006; Dehghani and Ataeepour, 2011; Mohamed, 2009).

Moreover, different researchers use different methods on reaching conclusions on geological data. Tutmez et al. (2012) used clustering based areal model in evaluating geo-environmental data whereas Başçetin (2007a, 2007b) used the selection of an optimal reclamation method; using an AHP-based model was evaluated for coal production

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in an open-pit coalmine. Also, Yavuz et al. (2008) applied AHP method using geological parameters for optimum support choice in a coalmine.

In this study, vibration analysis, formed using the commonly accepted PPV forecast equation, were studied for 12 years in a quarry located in Istanbul, Turkey. In each part of this study, it was notified that each output equation creates a different estimation. As the Analytic Hierarchy Process (AHP) was used, it was decided to use same field, where there are buildings, to carry out the excavation activity, and that the charge magnitude should be amplified in order to choose the best equation, verifying the most accurate output data in a 300 m distant field.

Since it would be necessary to amplify the charge magnitude for the excavation activity in a new practice in the same field, it was decided to use the Analytic Hierarchy Process (AHP) to choose the forecast equation that verifies the most accurate data by taking into consideration the buildings located in 300 m vicinity.

While using AHP, 102 vibration records were used as test data and classified according to distance and charge magnitude. For each group, estimations were made according to the previous years' equations. The error rate, number of data set, determination coefficient (r^2) and the year of equation obtained, were used as estimation criteria and their weighted percentage was set. The decision matrix and priority vector was obtained and the consistency analysis was made. Ranking values were finalized according to common evaluation by researchers who have been working on the field for the past 12 years.

2. Analytic hierarchy process (AHP)

Myers and Alpert first introduced the Analytical Hierarchy Process in 1968. In 1977 it was developed as model by Saaty, in order for it to be applied in problem solving and decision-making processes. This is a method of decision-making and estimation used in defining decision hierarchy and which involves a percentage breakdown of decision edges on factors effecting the decision-making process. AHP depends on individual comparisons based on level of importance in factors affecting decisions or the level of importance in such decision-making edges by using a pre-defined comparison scale. Finally, differences in the level of importance turn into distribution in percentage over the decision making line (Başçetin, 2007a, 2007b; Saaty, 1990).

Defining problem in decision-making has two phases. In the first phase, the points of decision-making are set. In other words, the answer to the question, “Decision shall be evaluated based on how many results?” is searched, where a comparison matrix (square matrix with n × n size) among the decision-making matrices are constituted. Here, the reciprocal importance level of each criteria is set. The comparison matrix is as follows:

$$A = \begin{bmatrix} 1 & a_{1n} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & 1 & \cdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix}.$$

In order to identify the importance of percentage distribution of the comparison matrix, column vectors, which constitute comparison matrix, are used and n is the number of the column vector B, with n variables constituted by using Eq. (2).

$$\boldsymbol{b_{ij}} = \frac{\boldsymbol{a_{ij}}}{\sum_{i=1}^{n} \boldsymbol{a_{ij}}} \quad B_i = \begin{bmatrix} b_{11} \\ b_{21} \\ \cdots \\ b_{n1} \end{bmatrix}_{n\times 1} \tag{2}$$

In the second phase, factors affecting the decision-making points are identified. For each of the defined criteria, an inter-alternative comparison matrix is constituted (Eq. (3)). In the aforementioned case the processes are repeated for each of criteria, N number of B column vector shall be constituted where in case these processes gather around, n ∗ n C matrix is constituted. By using C matrix, percentage distribution of importance, which implies reciprocal importance value of factors, are constituted. In order to do so, the arithmetic mean of the C matrix row is used to find out W column vector, which is referred to as the Priority Vector. The Priority Vector is calculated using the formula mentioned below (Başçetin, 2007a, 2007b; Tektaş and Hortaçsu, 2003; Timor, 2001):

$$\boldsymbol{w_i} = \frac{\sum_{j=1}^{n} \boldsymbol{b_{ij}}}{\mathbf{n}} \quad W = \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix}. \tag{3}$$

In order to check the consistency of the equation, consistency analysis is conducted. By using the Consistency Ratio (CR) (Eq. (4)), it is also possible to test the reciprocal comparisons among factors as well as the priority vector (Başçetin, 2007a, 2007b).

$$CR = \frac{CI}{RI} \tag{4}$$

Consistency index (CI) can then be determined using Eq. (5).

$$CI = \frac{\lambda max - n}{n - 1} \tag{5}$$

In order to calculate λ (Eq. (6)), first by multiplying comparison matrix A and W priority vector, column D matrix is formed.

$$\boldsymbol{E_i} = \frac{\boldsymbol{d_i}}{\boldsymbol{w_i}} \ (i = 1, 2, \ldots, n) \quad \lambda = \frac{\sum_{i=1}^{n} \boldsymbol{E_i}}{\mathbf{n}} \tag{6}$$

In order to calculate the consistency rate, a random value index (RI) is chosen. This value is constituted according to the number of alternatives in the decisions.

3. Test site

This study was carried out at the Akyol quarry, located in the Catalca district of Istanbul province, in Turkey. The location of the district, and the satellite image of the quarry, can be identified using the Google Earth program, as shown in Fig. 1. The distance from the quarry to the closest building in the village is around 300 m.

3.1. Geology

The Catalca district is located in Thrace basin, and a simplified geological map of this basin and vicinity are given in Fig. 2. In the study of Turgut and Eseller (2000), it was noted that there was a horst-like structure located in the east central part of the area, striking northwest–southeast, with crystalline basement rocks exposed in the central ridge near the town of Catalca (Turgut and Eseller, 2000). This structure is thought to be a recent rejuvenation, related to the activity of the Terzili fault zone on an old basement high that provided an isolated shoal environment on which reefal limestone from the Eocene age was deposited. Good outcrops of the whole Oligocene series are found on the faulted and uplifted southern margins of the study area. Complete sections of the shallow marine limestone from the Eocene age are exposed along the periphery of the northwest southeast, striking high and on the Northwestern margins of the area, where the crystalline basement rocks are exposed (Turgut and Eseller, 2000). At the quarry, limestone is produced to supply raw material to the construction industry in Istanbul province (Adiguzel, 2012). Rock mechanics and laboratory tests were performed on the limestone samples taken from the quarry and the results are given in Table 1 and petrographic properties are also given in Table 1 (Kalayci, 2011).