The Relationships between the Particle Velocity, Magnitude and Energy in the Blast-Induced Ground Vibration

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ABSTRACT
The level of blast induced vibrations is currently determined depending on the particle velocity and the frequency values. On the other hand, the earthquake hazard and the effects of earthquakes have been expressed with the size of magnitude by earthquake scientists. In this study, the aim was to determine the effect and magnitude of earthquakes generated by blast-induced ground vibrations and resulting earthquakes.

To this end, 10 blasting activities for overburden removal have been carried out and the related parameters have been measured with 7 seismographs and three accelerometers in open pit coal mine in Kangal-EÜAŞ (Electricity Generation Company). During the operation, all vibrations have been triaxially recorded in different directions and distances. Then, using the particle velocity values obtained from the measurements on the Richter scale magnitude and energy were calculated for blasting. Blast-induced ground vibrations showed a change of 1.5-2.6. in magnitude.

Key Words: Blast vibration seismograph, Accelerometer, Peak particle velocity, Magnitude, Energy

1. INTRODUCTION
The most important environmental impact induced by blasting is the ground vibrations. When the explosive is detonated, a very large amount of energy in terms of the pressure (50 GPa up to) and temperature (5000 up to) comes out (Hino, 1956; McKenzie, 1990; Cheng and Huang, 2001). Only 20-30% of the energy of the explosive is spent to break and to push forward rock mass, the rest of the energy is spent on undesired impacts such as ground vibration, flying rocks, noises, back fractures and excessive fractures (Hagan, 1973). In other words, while some part of the energy generated in consequence of the blasting is absorbed for the rock fragmentation, unabsorbed part is propagated circumferentially from blasting source to outward as seismic waves (body and surface waves) and causes the ground vibrations to reach even farther points than the blast site. Waves similar to seismic waves are created as a result of the blasts. The buildings, official structures and even historical artifacts near the blasting point are subjected to serious damages because of the ground vibrations generated by the blasts, and consequently national economy gets substantially damaged. These matters are submitted to the jurisdiction since many people and institutions are exposed to both economical and psychological damages. This situation introduces the need for accurately determining the behavior of the structures during the ground motion induced by the blast.
Ground vibrations need to be defined according to the parameters used in the definition of the earthquake in order to recover the damages of the buildings caused by the ground vibrations and to relieve people’s concerns and complaints about them. Magnitude is defined as a measure of the energy generated during the earthquake. It was defined as “the base-10 logarithm of the maximum amplitude of the ground motion measured in microns recorded by a special seismograph placed on a rough surface 100 km away from the epicenter” by Professor Richter in 1930s for the first time without any means to measure the energy directly. Different methods were developed for the measurement of the magnitude of the earthquake. These methods use the changes in seismic waves according to the magnitude and distance of the earthquake. While measuring the magnitude of the earthquake, it is necessary to choose the most suitable one of the methods scaled according to distance and magnitude interval of the earthquake (Richter, 1958; Bath, 1973). Nuttli and Richter scales were associated with particle velocity and scaled distance in order to determine the magnitude of the blast-induced ground vibrations (Richter, 1958; Nuttli, 1973; McGarr vd., 1981; Hedley, 1992; Jenask vd., 1993).

In this study, measurements on the blast-induced ground vibrations were performed by placing seismograph and accelerometers in the direction of the blast progression at the same distance and the same direction. Peak particle velocity and scaled distance of every component (East-West, North-South, and Vertical) obtained from the blast seismograph and accelerometers were subjected to statistical analyses and the relation between them was revealed; consequently the field constants of the land were determined. Then, by using the obtained empirical relation, the magnitude and energy of the blast were calculated according to Richter scale depending on peak particle velocity and scaled distance. Correlation coefficients were found by comparing the relations between particle velocity and magnitude of the blast and magnitude of the blast and energy, which were obtained for both methods.

2. GEOGRAPHICAL LOCATION AND GEOLOGY OF THE STUDY AREA
The working site is located in neighborhood of Kalburcayiri which lies 25 km south of Kangal County, approximately 100 km southeast of Sivas (Fig. 1). Kangal lignite basin is one of the important lignite reservoirs in Eastern Anatolia-Turkey and includes Hamal, Kalburcayiri and Etyemez lignite sites (Fig. 1). Lower Pliocene rocks in the Kangal basin are subdivided into two formations: the Kalburcayiri Formation and the Bicir Formation. The former consists of thick lignite seams and has been divided, on the basis of borehole data, into two informal units, a basal unit and a lignite-bearing unit. The basal unit consists of a fining-upward sequence of conglomerate, sandstone and claystone. Its thickness varies from 10 to 40 m across the basin. The lignite-bearing unit is represented, from the base upwards, by siltstone, claystone, lignite with mainly two benches (upper and lower seams), claystone and marl. Its thickness is between 30 and 60 m (up to 80 m from borehole data). The average thickness of each of the two seams in this mine is about 10 m, and they are separated by about 20 m of tuffaceous sedimentary rocks (Karayigit et al. 2001).
Fig. 1 Simplified geological map of the Kangal lignite basin (modified after Utku 1976; Narin and Kavusan 1993; Tercan and Karayığit 2001).

4.5-6 million tons/year coal resources with 600-1500 kcal/kg calorific value in above-mentioned site produced via open-pit method feeds a nearby thermal power plant with 457 MW capacities. The coal production in the site is carried out by open-pit method based on truck-excavator/dragline applications. Annual production ranges from 4.5 to 6 million tons; in return, 9-18 million m$^3$ overburden is removed. Blasting shots in the site are largely applied for loosing. Drilling machines 22 cm in diameter are used for drilling, length of bore holes ranges from 12 to 25m depending on bench height, and burden ranges from 6 to 14 m depending on formations. ANFO is used as an explosive substance.

2. MATERIAL AND METHOD

The most widespread parameters used to evaluate ground vibrations and vibration-related damages are frequency and peak particle velocity. The intensity of the ground vibration is affected by such parameters as the physical and mechanical properties of the rock mass, explosive characteristics and blasting design. It is important to predict the impacts of these parameters on blasting in order to use the energy of the blast efficiently in any rock mass and to minimize the undesired effects induced by the blast. Parameters such as maximum charge per delay, delay time, charge length, firing array and distance from the blast point, explosive types and geometric parameters of the blast affect propagation of seismic energy substantially. The magnitude of the blast can be calculated by using these parameters. Firstly, a relation between the scaled distance obtained by various blasting operations and Nuttli magnitude was established, and it was assumed that the propagation of the seismic energy generated during the blasting could be explained by the chemical energy in the explosive. A relation between peak particle velocity (mm/s) and distance (m) was established by Richter scale. For an exponential coefficient given in Equation 1, 0.33 was used for Nuttli scale coefficient and 0.57 was used for Richter scale coefficient (Richter, 1958; Nuttli, 1973; McGarr vd., 1981; Hedley, 1992; Jenask vd., 1993). It is calculated by using the
relation of the blast energy with Richter scale ($M_R$) given in Equation 3 (Gutenberg and Richter, 1956).

$$SD_R = \frac{R}{10^{aM_R}} = \frac{R}{10^{0.57M_R}}$$  \hspace{1cm} (1)

$$ppv = C \left( \frac{R}{10^{0.57M_R}} \right)^b$$  \hspace{1cm} (2)

$$\log E_s = 1.5M_R - 1.2$$  \hspace{1cm} (3)

$SD_R$ = Richter Scaled Distance (m)
$M_R$ = Richter Magnitude
$PPV$ = Maximum Particle Velocity (mm/s)
$b$ = Attenuation or decay factor of a seismic wave
$R$ = Distance from source to the location of interest (m)
$a$ = Proportionality exponent

It is necessary to measure the ground vibrations caused by the blasting activities precisely according to the distance and the quantity of the explosives. Different monitoring systems developed by different companies are used for these measurements. These recorders can determine three-component parameters of acceleration, velocity and displacement for each event (East-West (EW), North-South (NS), and Vertical (Z)) on the basis of time. Particle velocity gauges called as blasting seismographs and accelerometers are frequently used as measurement systems.

The measurements are made in nearby points to the residential areas by using the largest quantity of the explosives detonated at the same time in the blasting point. Blast seismograph and accelerometers were placed at 100-1200 m distances during the measurement of the blast-induced ground vibrations. All vibrations were recorded in different directions and distances during the measurement. Afterwards, the magnitude and energy of the blast were calculated according to Richter scale by using the particle velocity values obtained by both devices.

3. DATA COLLECTION AND EVALUATION

7 blast seismograph and 3 accelerometers placed in different directions and distances which are suitable for their purpose were used during the blasts between the dates 31 March-6 June 2012 in EÜAŞ (Electricity Generation Company) Kangal Coal Open Pit Mine Enterprise (Fig 2).
Measurements of 10 blasts were performed during the stripping activities between the dates 31 March-6 June 2012. During these blasts, 7 blast seismograph and 3 accelerometers which are suitable for their purpose were placed in different directions and distances. During the measurements, 69 blast seismograph three-component data and 24 accelerometer three-component data were recorded. Peak particle velocity and scaled distance of each component obtained from these measurements were exposed to regression analysis and the relations between them were established; consequently field constants of the land were determined (Fig 3 and 4).

As a result of the statistical analysis, the relation between peak particle velocity-scaled distance obtained from the blast seismograph and relation between peak particle velocity-scaled distances obtained from the accelerometer were found as an acceptable correlation coefficient in the range of 0.59-0.75 and 0.61-0.81, respectively. In the second and the last phase, the magnitude and energy of the blast were calculated according to Richter scale by using the field constants (Fig 5 and 6). Correlation coefficients were found by comparing the relations between particle velocity-magnitude of the blast and magnitude of the blast-energy which were obtained from both devices (Fig 7 and 8). As a result of the evaluations, correlation coefficients were obtained as acceptable relations.
Fig 3. EW component relation between particle velocity-scaled distance obtained from the Blast Seismograph

Fig 4. EW component relation between particle velocity-scaled distance obtained from the Accelerometer

Fig 5. EW component relation between particle velocity-Richter magnitude obtained from the Blast Seismograph

Fig 6. EW component relation between particle velocity-Richter magnitude obtained from the Accelerometer
4. CONCLUSION
The most complained one subject of the blast-induced environmental impacts is the blast-induced ground vibrations. Distance, scaled distance, frequency and particle velocity are the most commonly used parameters for evaluating the ground vibrations and related damages. Ground vibrations need to be defined on the basis of parameters used to define earthquakes in order to recover its damages on the buildings and negative effects on people. In this study, the blast seismographs and accelerometers were used to determine the environmental impacts of the ground vibrations in blasting activities in Sivas Kangal coal open pit mine enterprise. In the first phase, the blast-induced ground vibrations were measured by placing seismograph and accelerometer at the same distance and direction in the direction of blast progression. Peak particle velocity and scaled distance of every component obtained from the blast seismograph and accelerometers were exposed to statistical analysis and the relations between them were revealed; consequently the field constants of the land were determined. As a result of the statistical analysis, an acceptable correlation coefficient was found.

In the second and the last phase, the magnitude and energy of the blast were calculated according to Richter scale by using the field constants. Correlation coefficients were found by comparing the relations between particle velocity-magnitude of the blast and magnitude of the blast-energy which were obtained from both devices. When the results were evaluated, the magnitude of the blast-induced ground vibrations was found to be between the ranges of 1.5-2.6. The blasting activities were determined to be in a level that they could not cause any warnings or damages to the nearby buildings and environment.

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