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Simultaneous investigation of blast induced ground vibration and airblast effects on safety level of structures and human in surface blasting

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ABSTRACT

The significance of studying, monitoring and predicting blast induced vibration and noise level in mining and civil activities is justified in the capability of imposing damages, sense of uncertainty due to negative psychological impacts on involved personnel and also judicial complaints of local inhabitants in the nearby area. This paper presents achieved results during an investigation carried out at Sungun Copper Mine, Iran. Besides, the research also studied the significance of blast induced ground vibration and airblast on safety aspects of nearby structures, potential risks, frequency analysis, and human response. According to the United States Bureau of Mines (USBM) standard, the attenuation equations were developed using field records. A general frequency analysis and risk evaluation revealed that: 94% of generated frequencies are less than 14 Hz which is within the natural frequency of structures that increases risk of damage. At the end, studies of human response showed destructive effects of the phenomena by ranging between 2.54 and 25.40 mm/s for ground vibrations and by the average value of 110 dB for noise levels which could increase sense of uncertainty among involved employees.

1. Introduction

Drilling and blasting is the predominant method for rock fragmentation in large scale quarrying. Ground vibrations and airblast phenomenon from explosive sources are major challenges in surface mining. While the available energy releases, apart from useful usages for rock fragmentation and displacement, a considerable portion of explosive energy is wasting in the form of undesirable environmental side effects like ground vibration and airblast. This energy loss due to uncontrolled blasts not only can impose damages to structures and buildings, which are located in the vicinity of blasting operation but also causes serious annoyance to personnel and local residents. Most of mining companies are faced with the necessity of limiting ground vibration and noise levels in order to decrease or eliminate the possibility of damages or complaints [1,2].

Ground motion is the most important environmental side effect of rock blasting. Therefore, to elevate personnel safety and also protection of nearby structures against harmful effects of this phenomenon, blasting operation should factor in allowable limits and safe thresholds. Some regulations have been established by different researchers to form damage scales that are fundamentally based on peak particle velocity (PPV). Many investigations have been done to predict PPV, but the most accepted predictor equation was proposed by the United States Bureau of Mines (USBM) and is the most widely applied equation [3]. Also other modified predictors from other researchers such as Langefors and Kihlström, Ghosh and Daemen, Roy, Singh et al., Ambraseys and Hendron have been presented [4–8].

In spite of fundamental investigations focusing on stability and safety evaluation of buildings, previous research concentrates on blast-induced shock wave propagation and attenuation laws paying attention to frequency analysis. For example, Ak et al. discovered that 98% of the frequency values of blasting signals were between 4 and 40 Hz, and established the relationship between the PPV and the frequency spectrum [9]. Wu et al. recognized that the assessment of stability and safety of the structures can be done by using the main frequency of the blast-induced shock wave. Also, they revealed the main frequency attenuation law of the shock waves in relation to propagation distance, the charge weight, and the incident angle [10]. The frequency spectrum characteristics of blast-induced shock wave from foundation pit excavation were discussed by Tian et al. [11]. They revealed the

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relation between the frequency change rule and some factors such as distance, charge volume, blasting method, and elevation. Zhang et al. found out the capability of blast-induced micro-fissure in restriction of high-frequency vibration wave and the frequency mainly distributed in low-frequency band (20–95 Hz) [12]. Dogan et al. showed that PPV values for underground blasts are 47% to 95% smaller than surface blasts during evaluation of blast induced effects, and more than half of frequencies lie in interval of 10–15 Hz. Moreover, they indicated that for surface blasts, frequency distribution is clustered in ranges of 20–30 and 55–70 Hz [13]. However, in a more recent investigation carried out by Caylak et al., it is shown that ground vibrations show different spreading properties in different directions, depending on the geological structure of the region [14].

On the other hand, in every blast a portion of the total energy escapes into the atmosphere and causes unsavory problems, the so-called airblast. Air blasts are the air pressure waves generated by explosions. Regarding the importance of effectively controlling airblast-related problems, previous researchers have widely studied on the control of air overpressure and its effects [15–21]. Among them, the efforts of Siskind and Summers in spectral analysis of blast sounds and also proposing safe limits of sound levels should be noted [22]. It is worth mentioning that the human response studies and prediction approaches in the scope of blast induced air overpressure have been presented lately and should be pointed out. Mostafa discussed the capability of fuzzy logic and artificial neural network in prediction of ground and air vibrations [23]. Raina et al. investigated the response of human to ground and air vibrations [24]. Khandelwal et al. proposed a prediction model using an artificial intelligence methods "support vector machine" (SVM) and later Saadat et al. applied artificial neural network (ANN) to predict ground vibration in an iron ore mine [25,26]. In addition, Hajihassani et al. used a hybrid ANN to predict blast induced airblast overpressures [27].

There are regulatory limitations to control ground vibration and noise levels, which are applicable, if users just are aware of two parameters: the quantity of instantaneous explosive used and the distance from the blast. If the potential of damage exists, it is feasible to reduce ground vibration and noise levels to safe limits by using available damage criteria such as USBM, Office of Surface Mining (OSM) or DIN 4150. In this investigation the recorded events by using the USBM damage criteria were analyzed. In order to study characteristics of blast induced vibrations, air overpressures, and to evaluate the influence of these phenomena on personnel and nearby structures, seismic wave studies were conducted in Sungun Open-Pit Copper Mine. Previous studies were done by Azimi et al., concentrating only on the possibility of damage due to induced ground vibrations [28]. In this research, in addition to determination of attenuation equations for both of phenomena, human response studies and risk evaluation based on frequency analysis are carried out. Also, with the aim of reducing or eliminating risk of damage to structures and annoying influence of these two phenomena on the personnel, a practical blasting chart is proposed.

2. Ground vibration and airblast mechanisms

Detonation of explosive charge in the blast hole causes gas pressure on the hole wall and this sudden energy release deforms rock elements. Seismic waves are elastic waves and rock materials are significantly elastic and thus produce strong elastic or seismic waves when deformed [29]. The main purpose of rock blasting in mining activities is fragmentation. Therefore for the rock fracture, it is necessary that the amount of available energy exceeds the strength of rock or elastic limits. Rock fracturing occurs up to energy fall to a subordinate level, which is less than rock strength and stops. The residual energy will transmit through the rock and causes deformation but not fracture because it is within the elastic limits. This process leads to seismic wave generation.

Airblast is another type of blast energy dissipation, which is an atmospheric pressure wave transmitting into the surrounding area. The wave produced due to blasting operations, interacts with the air and elevates the air pressure from peak to ambient and drops to negative slowly, which can be described with time histories. This pressure wave consists of audible sound and sub-audible sound. The higher frequency portion (>15 Hz) of these pressure waves, which occurs in the near field (the region surrounding the blast site), is audible and the lower frequency portion lying in the infra sound (<15 Hz) region, which occurs in the far field (the region far from the blast site), is not audible but excites structures and in turn causes a secondary and audible rattle within a structure [30]. Bhandari classified the factors which influence ground vibration and air overpressure levels as controllable and uncontrollable (Fig. 1).

3. Sungun open-pit copper mine

3.1. Brief description and geological properties

Sungun, an open-pit copper mine with a mineable reserve of 410 million ton, is planned to produce 7 million ton ore for the initial 7 years with the intention to expand capacity up to 14 million ton ore with an average grade of 0.6% copper, is located 100 km north east of Tabriz city, Iran (Fig. 2). The Sungun intrusive complex hosting the Sungun porphyry copper stock intruded along the Sungun anticline into cretaceous limestone, marls and shales. The main lithological units exposed in the Sungun pit are Sungun porphyry (SP), dykes, pyroclastics (PC), trachybasalt (TB) and skarn (SK) (Fig. 3).

3.2. Blast design parameters

In drilling operation, blast holes were drilled vertically with staggered drill-hole pattern and in blasting operation, Ammonium Nitrate Fuel Oil (ANFO) is used as main blasting agent and Non-Electric (NONEL) and detonating cord as initiation systems. Also, inter-row sequencing was adopted. Ranges of general blast design parameters are presented in Table 1.

3.3. Field measurements

The seismograph used during this survey was Minimate Pulse produced by Instantel (Fig. 4). Recorded data from 22 production blasts include three perpendicular velocity components of the longitudinal (V_L), the transverse (V_T) and the vertical (V_V). Other obtained information by seismograph is frequencies or duration of vibration, acceleration, peak vector sum (PVS) and air overpressure level for each of events. Maximum instantaneous charge is

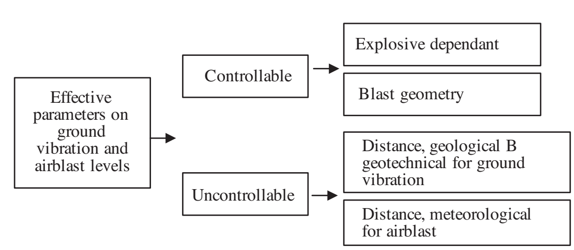

Fig. 1. Effective parameters on ground vibration and airblast levels.