CHAPTER 1
INTRODUCTION

1.1 Background and motivation

Blasting is one of the most economical methods used for fragmenting rock mass. However, rock blasting causes a number of nuisances, such as ground vibration, air overpressure, fly rock, dust etc. It is consequential to state that merely 20-30 % of the explosive energy is used to fragment and displace the rock mass, while the rest is dissipated in the form of ground vibration, air blast, noise, and fly-rocks, etc. (Uysal et al., 2008). Further the impact of efficacy is also assessed by evaluation of powder factor (PF). The PF impacts secondary breakage and the diggability of the excavators.

Today, the world population is more than 7.71 billion, and the figure is continuously growing every day. In simple terms, it means that every year approximately 10 tons of material is to be extracted through opencast mining for fulfilling the basic needs of every person in the world (Anon, 2017). If one looks ahead, the United Nations (UN) predicts that the world's population will attain 9.2 billion people in 20 years, by the year 2039. By simply applying the present consumption rate of 10 tons per person, one would anticipate the quantum of material to be mined out yearly through opencast mining to increase around 90 billion tons. It is interesting to mention here that about 95% of the population growth is currently represented by the developing countries of the world. Based on the expectations for improved living standards of this population in the future, the actual estimate of materials mined using opencast mining method in the year 2038 is 138 billion tons (Bagherpour and Tudeshki, 2007). Hence it necessitates the construction and commissioning of new opencast mines as well as expanding the size of existing mines to satisfy the basic requirements of population, primarily in the infrastructure and energy sectors dominated by minerals such as coal, iron, limestone, copper and aggregate stones.

In India, the requirement of coarse aggregates is expected to be 2.5 billion MT per annum by 2020, with a market size of Rs 750 billion to fulfil an ever-growing demand of the infrastructure sector (Sharma et al, 2018). These coarse aggregates are produced from raw stone boulders, which are obtained from a stone quarry through the conventional cycle of operations including drilling and blasting. Similarly, India is the second largest cement producing country in the world and having around 210 heavy-capacity cement plants (possessing an installed capacity of 410 MT/annum) in 2020. Additionally, more than 350 small capacity cement plants (possessing capacity of around 11.10 MT in a year) contribute to the production volume. Limestone is the most extracted mineral in India with the cement industry being the principal user. There were 650 limestone mines in 2020-21 and labour employment in limestone mines was reported as 17,800 during the same year. Cement, Chemicals, Fertilizer, Foundry, Paper and Steel industries are the major consumers of limestone produced in India. Both limestone and aggregate stone quarries are worked by open pit method in India. Among these quarries, a few are captive and mechanised, which provide feed to cement, iron and steel units. The mining method involves the material preparation through drilling and blasting in both limestone and aggregate stone quarry. The major concern areas of blasting operation are productivity, environmental hazards and safety. The productivity is related with obtaining desired size of fragments and powder factor with high emphasis on reduction of blasting nuisances. Since about 80% of the energy transferred to the rock mass is lost in the form of ground vibration and noise, it is crucial to enhance the proper usage of explosive energy towards breaking the rock (Clay and Huang, 2000). This unutilised energy produces undesirable and unavoidable environmental effects causing damage to the nearby civil structures. In the current scenario, as the mining operations are increasing in areas close to human settlements, ground vibrations due to blasting and their transmission in rock mass requires significant attention. Therefore, the public perception has become very negative, largely due to a host of blasting nuisances in recent years. Unless the blasting impediments such as ground vibration, air overpressure, fly rocks and dust generation etc. are controlled, such problems can be expected to increase as a result of the unceasing urban sprawl into areas around blast sites. Therefore, any quarry must incorporate the reduction in blasting nuisances and increasing blasting productivity by identifying the influencing blast design parameters on reducing blasting nuisances and enhancing the PF.

The increasing production of minerals is setting a trend for large opencast mine with high stripping ratios. The requirement of rock excavation is surging. The rock fragmentation by blasting plays a significant role in the unit operations being carried out in the quarries. The productivity and economic benefits of the unit operation rests on the blast designs that produces adequately fragmented rocks. However, the degree of fragmentation is governed by many factors, the most influential being the way in which the explosive energy is utilised in a blast as excessive energy can cause significant damage to the environment through undesirable effects such as ground vibrations (Berta, 1990). Presently, the mining operations of many of the limestone and aggregate stone quarries are existing at very close proximity to the habitations, highway and sensitive structures. Hence it necessitates certain practical measures required to be adopted for reducing the blast induced damage such as ground vibration when the blasting operation is carried out in such mines. Efficient blast designs are needed to ensure that the Blast Induced Ground Vibrations (BIGV) are maintained below the threshold limits imposed by the regulatory agencies. Thus, a controlled blast design is significant to safeguard and protect the structures in the vicinity of the mine from the BIGV effects.

Even in a properly designed blast, only a portion of the total energy of the explosive is used for fragmenting and displacing the rock and the rest is wasted off in producing undesirable environmental and other adverse effects like ground vibrations, fly rock, air overpressure (noise), air pollution, over-break and production of oversize boulders making them an integral part of blasting (Chen et al., 2019; Ding et al., 2020; Yang et al., 2020). Spathis (1999) and Sanchidrian et al., 2007) report that energy consumed by vibration of ground is about 3-12% of the energy generated in the form of heat of explosion, which attributes to 60-70% of energy transmitted to rock. These undesirable effects cause damage to the civil, mining, defence structures and other properties in the vicinity. With increasing mining and construction activities in areas close to human settlements, ground vibration has become a critical environmental issue as it can cause human annoyance and structural damage.

The use of blasting technology in civil and mining operations, particularly when carried out near residential areas, leads to at least two serious problems: (i) Complaints by local residents about explosion-induced vibrations; (ii) Confronted by various laws and legal responsibilities levied by government against the blasting nuisances. These nuisances hinder the production, thereby wasting time and rendering the projects ultimately uneconomical (Amiri et al,. 2020).

Human beings are very sensitive to these nuisances and can detect even very low level of vibrations (as low as 0.5 mm/s) which cannot cause damage to the structures. Vibration levels lesser than the ones that cause damage to the structures could cause rattling of doors or windows. Many a times, the slamming of a door or passing of a loaded lorry by the side of the house generates more vibration than a quarry blast.

However, residents become alert and inquisitive by noise and rattling of objects in the immediate surroundings due to blasting in the neighbourhood and start looking for the damages to the structures like cracks in the walls in their residence. Finding a crack that existed even before blasting activity commenced in the neighbourhood, but not noticed, people start worrying attributing the crack to blasting activity.

Dowding (2000) observed that the human sensitivity gets triggered by vibrations and air blasts and becomes inquisitive and suspicious about them from a blasting activity in the vicinity reaching the structure and resulting in some form of damage to it. The tolerance and reactions of humans to vibrations vary from person to person, the nature of the work he/she is doing, the environment in which they are present at the time of blast, etc. Blast induced ground vibrations may result in annoyance and interference with work proficiency.

The parameters affecting ground vibrations can be classified into two categories, namely the controllable parameters and the uncontrollable parameters (Yang et al., 2020; Bhandari 1997; Sadat et al., 2014; Hasanipanah et al., 2017). Controllable parameters are primarily associated with the blast design and explosive attributes such as blast hole diameter, burden, stemming, no. of rows, depth of blast hole, charge weight per delay, spacing, powder factor etc., which can be duly engineered by the blasting professionals. Uncontrollable parameters are structural formations and rock properties, which cannot be altered (Hasanipanah et al,.2018).

The charge per delay and the distance of the blasting site from the structures are the conventional factors on which the designers conduct the blasts according to the site conditions. However, it is mandatory to have a clear understanding of the causes or factors, which influence generation, and propagation of ground vibration such that the ground vibrations are kept within desired levels.

Presently, the mining operations of many of the limestone and aggregate stone quarries are extending very close to the habitations, highway and sensitive structures. Hence it necessitates certain practical measures required to be adopted for reducing the blast induced damage such as ground vibration when the blasting operation is carried out in such mines. While it is generally recognized that both shock and gas energy assists in the rock fragmentation process, the precise nature of the mechanism of rock fragmentation as a result of detonation of an explosive charge is not fully understood (Singh et al., 2016). However, it was reasonable to accept that properly designed blasts utilize the majority of explosive energy to break the rock and leads to desired powder factor and poorly designed produces higher vibration levels due to waste of energy. It requires efficient blast designs to ensure that the ground vibrations are maintained below the threshold limits imposed by the regulatory agencies. The regulatory agencies are the United States Bureau of Mines (USBM) RI 8507, DIN and Director general of mine safety (DGMS). The regulatory limits of USBM and DIN on PPV and frequency has been shown in Table 1.1. The potential damage at low frequency range (< 40 Hz) is significantly higher than those at high frequency range (> 40 Hz). This is because of the effects of resonance at the natural frequency of structures and buildings that ranges in between 5-16 Hz (Ak et. Al; 2009). Hence, if the values of PPV is plotted in conjuction with frequency and they fall within the inside region, where the frequency is always greater than 40Hz, is considered to be safe.

Table 1.1: Regulatory limits of ground vibration as per USBM and DIN criteria.

USBM-RI8507			DIN-4150			
Structure	PPV (mm/s)		Structure	PPV (mm/s)		
	$< 40Hz$	$\geq 40Hz$		$10Hz$	$10 - 50Hz$	$50 - 100Hz$
Modern homes dry	18.75	50	Industrial Buildings	20	20-40	40-50
Wall interiors			Residential Buildings	5	5-15	15-20
Older homes	12.75	50	More Sensitive buildings	3	3-8	8-10

As per the Indian standard as specified by the Director General of Mines Safety, the regulatory limits in terms of PPV and frequency of ground vibration are tabulated in Table 1.2 (DGMS, India, 1997). Therefore, it is implicit that for thorough investigation of blasting vibrations, measurement of frequency as well as PPV is essential.

Table 1.2: Safe blasting limits as per DGMS.

Type of structures	Dominant excitation frequency (Hz)		
	< 8 Hz	8-25 Hz	>25 Hz
(A) Building/Structures not belonging to owner			
(i) Domestic houses/structures	5	10	15
(ii) Industrial buildings	10	20	25
(iii) Sensitive structures/buildings	2	5	10
(B) Building belong to the owner with limited span of time			
(i) Domestic houses/structures	10	15	25
(ii) Industrial buildings	15	25	50

Besides, human response and the variability of response are probably just as important as damage to buildings, etc (Venkatesh, 2005). Therefore, blast-induced vibrations should be controlled strictly during blasting near residential areas (Dowding, 2000). Thus, a controlled blast design is significant to safeguard the persons employed and the protection of nearby structures from the blast-induced ground vibration effects.

Currently, several methods including small scale physical models, analytical and numerical models, reduced scale field tests and full-scale fields tests have been adopted for prediction of blast- induced damages such as vibrations in the field of blasting research. Besides, various researchers have made attempts to develop computer models to estimate the complete block size distribution and to study its influence on fragmentation.

It is necessary to ponder upon the value of powder factor in order to make a balance between explosive consumption and fragmentation desired. Besides, a lot of innovation has been attempted to improve the blast results especially in the area of blast induced ground vibration and powder factor. Frequency of the blast waves, peak particle velocity (PPV), displacement and acceleration of the particles is important parameters associated with ground vibration. Among these parameters, PPV is considered as the most important criterion to study the structural damage (Kumar et al., 2016; Hasanipanah et al., 2017; Fattahi and Hasanipanah,2020). PPV is generally dependent upon the explosive charge weight per delay and radial distance together with site constants which depend upon the condition of rock mass (Chen et al,.2019; Amiri et al,.2020; Yang et al,.2020). The thrust area of the research has been to select the blasting design and explosive parameters affecting PPV and PF for controlling the ill effects of blasting, and improve for better powder factor. Many studies have been conducted earlier using only a limited number of controllable blast design parameters affecting PPV and PF. (Khandelwal and Singh, 2009; Gorgulu et al.,2015; Rezaeineshat et al.,2020; Jong and Lee, 2004; Rai et al., 2009; Mohamed et al., 2015; Agyei and Nkrumah, 2021). However, only a limited number of studies have been carried out including almost all the controllable blast design parameters.

1.2 Statement of problem

The purpose of blasting operations is rock fragmentation. Proper blast design and execution provides appropriate rock material granulation that is suitable for loading and transportation.

The blasting process and usage of explosives remain a potential source of numerous blasting nuisances such as ground vibration, fly rocks, air overpressure etc. The judicial consumption of the explosive is essential for effective blasting. In blasting, powder factor is used to estimate the explosive consumption. Hence it becomes important to evaluate the PF in order to reduce the nuisances due blasting.

The blast induced ground vibration is one of the significant ill-effects of blasting. Usually, the blast-induced ground vibration is evaluated and measured by using peak particle velocity, frequency, and duration time. Among these three indexes, peak particle velocity (PPV) is the most common and widely used index (Hasanipanah et al., 2017; Nguyen et al., 2019).

The conventional techniques to predict the PPV includes only two parameters, one is amount of explosive per delay and other is distance of measuring point from the blasting round. Currently, several methods including small scale physical models, analytical and numerical models, reduced scale field tests and full-scale fields tests have been adopted for prediction of blast-induced ground vibrations in the field of blasting research. Various researchers have predicted the ground vibration in terms of PPV with taking only two attributes, namely the amount of explosive and distance from the blast side to the monitoring point (Khandelwal and Singh, 2007; Khandelwal, 2011; Hasanipanah et al., 2015). However, there are numerous parameters that can influence the peak particle velocity, depending on blasting design parameters and explosive parameters. There are several possible combinations of blasting design and explosive parameters that affect powder factor also. Owing to multiplicity of blast design parameters and complexity of interactions among these parameters, empirical approaches may not be convenient for efficient blasting design. In such a complex situation, the use of state-of-art techniques such as PCA and SSE may be useful. Apart from this, outside the statistical domain, the artificial intelligence (multi-layer perceptron ANN) techniques have been very authentic to validate the possible equation developed by PCA and SSE.

1.3 Objectives of the study

The present work contributes by developing equations using principal component analysis (PCA) and step-wise selection and elimination (SSE) statistical technique. The proposed equation is validated (within the statistical domain), and verified (outside the statistical domain) by employing multi-layer perceptron (MLP) artificial neural network (ANN) technique. The objectives of the present study are summarised as:

i. An investigation into the correlation among various blast design parameters on peak particle velocity and powder factor in open pit quarries.
ii. Development of statistical equations by investigation of blasting design parameters and critical assessment of their impact on powder factor (PF) and peak particle velocity (PPV), in a number of open pit limestone quarries using principal component analysis (PCA) and stepwise selection and elimination (SSE) followed by multi-variate linear regression (MLR) technique.
iii. Validation of the statistical equations (within the statistical domain) developed by statistical tools- PCA and SSE for PPV and PF in open cast quarries.

iv. Comparison of the developed equations for PPV prediction with the predicted values using standard United States Bureau of Mines (USBM) Square root equation.

v. Verification of the proposed equations (outside the statistical domain) by application of Artificial Intelligence (AI) tool- MLP based ANN technique.

1.4 Organization of the thesis

This research work comprises of 7 chapters which aimed at a broad discussion and conclusions.

Chapter 1 defines the research problem, Introduction, the objectives and the scope for research work.

Chapter 2 presents the intensive literature review on the mechanism of blasting, propagation and prediction of ground vibrations (PPV) due to blasting and the powder factor (PF) desired for better blasting results, factors affecting ground vibrations, seismic waves, the summarized table of works done by different researchers in the field related to this study with year and their conclusions.

Chapter 3 describes briefly about the quarry sites. Blast induced ground vibration (PPV) and powder factor (PF) monitoring at 3 different experimental sites in the same opencast limestone quarries. A brief discussion about the instruments used is also presented in this chapter.

Chapter 4 describes the Research methodology, which have been carried out to obtain the results. It includes the recording of PPV and, measurement PF.

Chapter 5 describe the results obtained with the help of methodology followed. The results in the form of equation, which shows how the various parameters affect the PPV. The discussion on all the results obtained are also described in this chapter.

Chapter 6 describe the results obtained with the help of methodology followed. The results in the form of equation, which shows how the various parameters affect the PF. The discussion on all the results obtained are also described in this chapter.

Finally, Chapter 7 summarizes the results and findings based on analyses of the results as discussed in the preceding chapters. In the end, the chapter outlines the recommendations for future work which could not be undertaken due to paucity of time and non-availability of resources.