1.0 INTRODUCTION

The nation's economy depends heavily on the energy resources like coal. In India, the largest proportion of coal is consumed in electricity generation. Fortunately, India is blessed with huge coal reserves. The total coal reserves of India stands at fifth position in the world. (i.e. 319.04 billion metric tonnes). Further, India is the second-largest coal producing country in the world. Indian coal reserves comprise of sub-bituminous to bituminous coal reserves with different grades and ages since the Gondwana period. A smaller portion of lignite coal (i.e. 45.66 billion metric tonnes) reserves of tertiary age are also found in India. (The Wire, 2020). Open-cast mines produce over 96% of the coal in the different regions of India. For this, on a large scale, drilling and blasting is adopted. The health and environmental impact of the coal industry is profound, and phasing out coal would have short-term health and environmental benefits, greatly exceeding the costs (Zhongming et al. 2020). Blasting is an integral part of the mining and quarry industry till date and its overall environmental impacts creates serious concerns of people close to mines and quarries. In mining, rock fragmentation refers to the breaking of hard rock into suitable sizes to ease handling and processing. Drilling and blasting, which uses commercial explosives (placed in blast-holes) to break down a rock mass into pieces when they detonate, is now the most practical and extensively used method of ground fragmentation (Abbaspour et al. 2018; Yu et al. 2020; Bayat et al. 2021).

Blast-induced energy (BIE) causes damage, is hazardous, causes human discomfort, and severe environmental impacts. The distribution of blast-induced energy takes different forms like desired (20-30%) for causing fracture of in-situ rock displacement of the broken rock mass to a certain distance from the original position, etc. and undesired (70-80%) such as; ground vibration, air overpressure, fly rock, and other noises. Blast-induced ground vibration is a major bye product of blasting that still eludes perfect understanding, estimation and prediction as it is interplay of the complex non controllable and controllable factors. (Monjezi et al. 2012; Raina 2014; Armaghani et al. 2014; Armaghani et al. 2014; Marto et al. 2014; and Ebrahimi et al. 2016). In numerous mining countries, including Ghana, India, Brazil, Turkey, and South Africa, incidents of regular complaints have been reported that, in some circumstances, erupt into protests against mining operations because of blast consequences (Bansah, et al. 2016; Torres, et al. 2018; Agrawal and Mishra, 2020). Efforts are ongoing to reduce Blast-induced ground vibrations through optimising blast design, blast hole dimensions, blasting accessories, and explosive parameters. The chief aim is to ensure that the structures in the vicinity of the mines and quarries are not damaged. Several studies were carried out to predict and analyze the blast-induced ground vibration nearby the limestone quarries. Some of the recent studies were reported by (Elseman 2000; Chen and Huang 2001; Tripathy and Gupta 2002; Adhikari et al. 2004; Kahriman 2004; Kuzu and Ergin 2005; Singh et al. 2006; Ozer et al. 2008).

Several counties like the United States of America, Britain, Germany, Australia, and India, have developed the structural damage criteria standards based on peak particle velocity for the different range of frequencies. Several regulatory agencies started interpreting, analyzing, and assessing ground vibration for seven to nine decades (Siskind, 1980). The regulatory agencies established the vibration standards for the safe environment, structures and human comfort. The scientists (Crandell, 1949; Morris, 1950; Duvall-Fogelson, 1962; Wiss, 1968; Nichols et al. 1971; Medearis, 1977; Siskind et al. 1980; Dowding, 1996) developed more than dozens of peak particle velocity predictor model equations to predict the ground vibrations produced due to blasting. They tried to establish the correlation between the ground vibration parameters (like displacement, velocity, acceleration, and frequency) with its effects like human discomfort and damage to structures. Finally, the correlation between them was established to a great extent and trends could be obtained using these equations.

However, such approaches only considered the limited number of parameters influencing ground vibration and air overpressure, even though this phenomenon is also influenced by other controllable and uncontrollable parameters such as; blast geometry and geological conditions (Douglas 1989; Singh and Singh 2005).

During the explosion, the dynamic stress-energy is released around the blast holes. This stress-energy produces elastic deformations and waves propagating outward from the blast site in the form of seismic waves (Jaeger and Cook, 1979).

Ideally, when the source of blasting is spherical in a homogeneous medium, then only compressive motion is generated. However, the explosives used under operating conditions within the blast-holes are not spherical and the medium is also not homogeneous. Hence, the blasts result in generation of several types of seismic waves during blasting (Grover, 1973). Two types of seismic waves are predominantly generated like the first one is body wave, comprising of *P*-waves and are also known as compressional, primary or longitudinal waves and *S*-waves that are known as shear, secondary or transverse waves. The second type is surface waves, that includes Rayleigh (*R* wave) and Love waves (*Q* wave). Seismic waves are generated by natural sources as well as artificial ones. The body and surface waves propagate with different paths in the same medium. Induced seismicity refers to typically minor earthquakes and tremors caused by human activity that alters the stresses and strains on the earth's crust. Most induced seismicity is of a low magnitude.

A few sites regularly have larger quakes, such as the Geysers geothermal plant in California, which averaged two events of 4 magnitudes and 15 events of 3 magnitudes every year from 2004 to 2009 (Anderson, 2016). The Human-Induced Earthquake Database (*Hi Quake*) documents all reported cases of induced seismicity observed on scientific grounds and is the complete compilation of its kind (Wilson et al. 2017 and Foulger et al., 2018). Charles Francis Richter, in his landmark 1935 paper, termed the Richter's magnitude scale as the "magnitude scale". It has since then been used to measure the strength of earthquakes (Kanamori, 1978). Later, this was revised and renamed the local magnitude scale, denoted as ML or M_L. When Richter proposed the resulting scale in 1935, he worked on it upon Harry Wood's suggestion for a "magnitude" scale. "Richter magnitude" appeared to have originated when Perry Byerly told the press that the scale was Richter's and "should be referred to as such." (Richter, 1935). In 1956, Gutenberg and Richter, while still referring to "magnitude scale", labelled it "local magnitude", with the symbol M_L , to distinguish it from two other scales they had developed, the surface wave magnitude (M_S) and body-wave magnitude (M_B) scales (Gutenberg and Richter, 1956).

The intensity of blast-induced ground vibration mainly depends on natural parameters that are uncontrollable and artificial parameters that are controllable. Seismograph used to measure different parameters such as; peak particle velocity PPV, frequency, and peak vector sum PVS, etc., for analysis and interpretation of blast-induced ground vibration BIGV.

Ground vibration decreases exponentially with distance. Different researchers made the prediction of blast-induced ground vibrations at different levels. Generally, the prediction is based on scaled distance SD (maximum charge per delay and distance) models and numerical simulation modelling such as; artificial neural network ANN, multivariate regression analysis MVRA, finite element method FEM, and fuzzy inference system FIS, etc. Artificial neural network is one of the recent research in the field and has found various applications in science and engineering. Back-propagation artificial neural network is a common technique of training ANN to minimize the objective function. However, it has been proven that the back-propagation ANN algorithm can easily converge to any local minimum, and it cannot guarantee convergence in learning (Lee et al. 1991; Priddy and Keller 2005; Adhikari and Agrawal 2011). Khandelwal and Singh (2009) utilized the artificial neural network and multivariate regression analysis models to predict peak particle velocity and frequency by incorporating rock properties, blast design, and explosive parameters. Fisne et al. (2011) utilized a fuzzy logic algorithm and regression analysis to predict the peak particle velocity using 33 datasets obtained from the Akdaglar quarry in Turkey.

Ground vibration is today assessed using an artificial neural network (ANN), multivariate regression analysis (MVRA), and different attenuation models. Linear regression analysis (LRA) helps determine the characteristic site constant of the rock mass to establish the straight-line equation and correlation coefficient between measured and predicted values.

1.1 Research Problem

Several impacts like ground vibrations, air overpressure, fly rocks, dust cloud of fine particles, and noise are produced behind the blasting operation. This study covers the effects of blast induced ground vibrations over nearby structures along with the blast geometry and the explosive parameters.

During blasting operations, several negative impacts like ground vibrations, air overpressure, fly rocks, dust cloud of fine particles, and huge noise is produced. Of these, the blast induced ground vibrations is the most severe impact as it not only discomforts people but also damages the structures nearby the mines and quarries.

Blast induced ground vibrations cause short durational and long durational impact as enlisted below:

Short durational impacts of ground vibrations:

- Impact on the nearby structures
- Impact on the people
- Environmental impacts

Long durational impacts of ground vibrations:

- Impact on the nearby structures

- Gradual destabilization of the overburden dumps, if any
- Impact on mine haul roads
- Impact on the surface water (migration)
- Impact on ground water (migration)
- Impact on aquifers and reservoirs

During blast induced ground vibrations, duration of vibrations, number of the repetitions, and repetition rate of ground vibrations directly contribute to the probability of the damages. The structures develop hairline to major cracks on the surface or even severe structural damage due to such blast induced ground vibrations. The problems associated with the blast induced ground vibrations need precise and accurate identification and possible solutions in the field through continuous monitoring and analysis. For minimising these damages, suitable blast design, expolsives, and blasting accessories needs to be selected.

1.2 Research Objectives

The objectives for the present study are:

- To qualitatively assess the impacts of BIGV on nearby structures.
- To establish limits of the zones of destractruction for maximum charge per delay.
- To obtain the safe charge weight per delay for different distances under observation.
- Comparative analysis of the performance and suitability of predctor models, BPANN, and MVRA techniques.
- To determine the site constants for in-situ rock mass.

1.3 Methodology

The research methodology comprised of literature review, field survey, and recording of the data of various parameters of ground vibrations in different mines and quarries, and the analysis of the data from the experimental blasts. These data were processed and analysed through the various models like linear regression analysis, empirical attenuation models, multivariate regression analysis, and back propagation artificial neural network. In order to identify the impacts of the blast induced ground vibrations and minimise the risk of damages to the structures, efforts were made to assess and predict the peak particle velocity and the dominant frequency. The predicted values were compared with the measured values to evaluate the correlation between them.

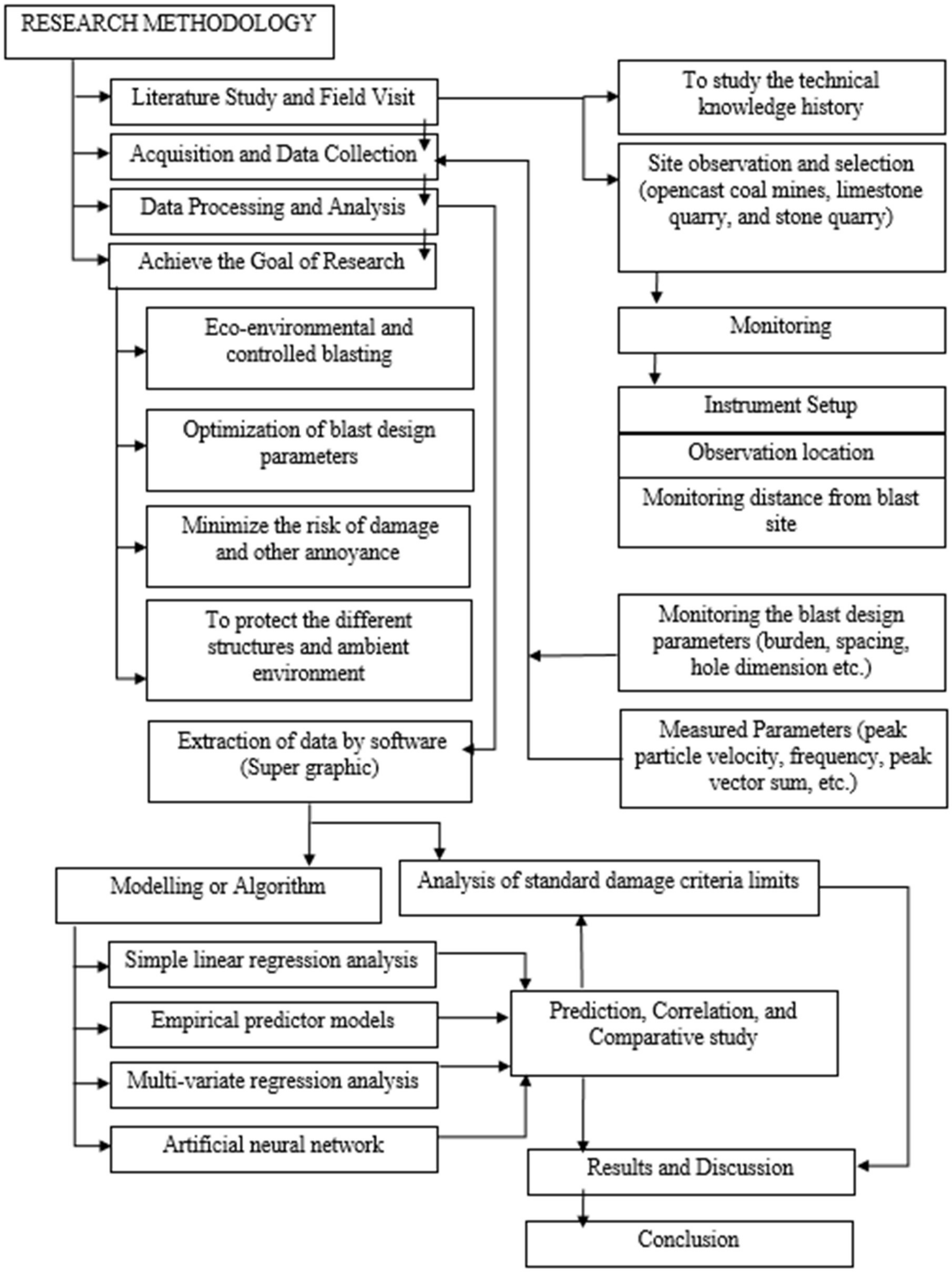

Figure 1.1 Flow chart of the research methodology

1.4 Significance of work

Significance of the work is to evaluate the blast design in eliminating blasting associated nuisance. The improvisation in blast designs would be obtained through the predictor equations.

On the basis of the field experiments and the analysis, the research contributions are significant in:

- Development of methodologies for the estimation of safe charge weight per delay in the selected mines and quarries.
- Development of methodologies to identify the significant parameters of blast-induced ground vibrations.
- Qualitative and quantitative assessment of the damage level of different structures due to blasting.

1.5 Organization of Thesis Work

The content of the present thesis work is organized according to the following chapters:

Chapter 1 broadly introduces work done and presented in the thesis. It discusses the context and the objectives of the research. It elaborately attempts to understand the ground vibrations and its environmental impacts. Further, the different methodologies and the computational models being adopted by the scientific community for establishing the correlation between ground vibration and its impacts are covered. It also provides for the scope of future work and the organisation of the thesis.

Chapter 2 covers the literature review representing the state-of-the-art literature on the area of research and the detailed study about the related topics. It elaborates various field conditions their field parameters for analyzing the ground vibrations and its impacts. A detailed investigation has been carried out of the various applications and algorithm-related aspects along with their historical growth.

Chapter 3 reports the efforts of data acquisition, describing the the different field area, their locations and the non-controllable parameters and the controllable parameters as exisitng in reality. Thus it provides detailed study of the field condition and the data monitoring carried out during the study.

Chapter 4 of the thesis describes the data processing, analysis, and qualitative and quantitative interpretation of the structural damages caused by vibration. Structural damages are scaled by the pre-established standard damage criteria scale. Various conventional and computational methods in use for assessing the blast-induced ground vibrations over the community surrounding various mine and quarry areas is also discussed.

Chapter 5 covers the results and the discussions portion of this work; that represents the structural response and human discomfort to ground vibration at different monitoring distances for the open-cast coal mines and stone quarries. It covers the efforts for establishing correlation between damage and vibrations.

Chapter 6 of the thesis sums up the conclusions of the work, drawn from the total work- field, data analysis and computational efforts and ANN. It also provides for the recommendations for future work.

1.6 Scope of the Research

The researchers taking this kind of work in future should try to go for:

- Drone based high speed videography per-blast and post-blast survey to delinate the precise impacts over structures of the BIGV.
- Numerical modelling of the blasting as a dynamic phenomena be adopted for larger flexibility and accuracy in prediction of structural daamges due to BIGV.