

**DEDICATED TO MY BELOVED
PARENTS**

**FOR THEIR LOVE, SUPPORT AND
ENCOURAGEMENT**

CERTIFICATE

It is certified that the work contained in the thesis titled **“Evaluation of Blast Induced Ground Vibration and Powder Factor in Surface Limestone Quarries Using Statistical and ANN Approach** “by *"PUNIT PAURUSH"* has been carried out under our supervision and this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

Prof. Piyush Rai
(Supervisor)
Department of Mining Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, INDIA

Dr. Suresh Kumar Sharma
(Co-supervisor)
Department of Mining Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, INDIA

DECLARATION BY THE CANDIDATE

I, "**PUNIT PAURUSH**", certify that the work embodied in this thesis is my own bonafide work and carried out by me under the supervision of "**PROF. PIYUSH RAI**" and co-supervision of "**DR. SURESH KUMAR SHARMA**" from "**JULY 2015**" TO "**JULY 2021**", at the "**DEPARTMENT OF MINING ENGINEERING**", Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that, I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, *etc.*, or available at websites and have not included them in this thesis and have not cited as my own work.

Date:

Place: Varanasi

Punit Paurush

CERTIFICATE BY THE SUPERVISOR

It is certified that the above statement made by the student is correct to the best of my knowledge.

Prof. Piyush Rai
(Supervisor)
Department of Mining Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, INDIA

Dr. Suresh Kumar Sharma
(Co-supervisor)
Department of Mining Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, INDIA

Prof. Piyush Rai
(Head of Department)
Department of Mining Engineering
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, INDIA

COPY RIGHT TRANSFER CERTIFICATE

Title of the Thesis: “Evaluation of Blast Induced Ground Vibration and Powder Factor in Surface Limestone Quarries Using Statistical and ANN Approach”

Name of the Student: Punit Paurush

Copyright Transfer

The undersigned hereby assigns to the Indian Institute of Technology (Banaras Hindu University) Varanasi all rights under copyright that may exist in and for the above thesis submitted for the award of the "*DOCTOR OF PHILOSOPHY*".

Date:

Place: Varanasi

(PUNIT PAURUSH)

Note: However, the author may reproduce or authorize others to reproduce material extracted verbatim from the thesis or derivative of the thesis for author's personal use provided that the source and the Institute's copyright notice are indicated.

ACKNOWLEDGEMENTS

Through this page, I offer my salutation to Mahamana Pt. Madan Mohan Malviya Ji, the creator of this pious seat of learning.

It is indeed my proud privilege to express my deep sense of gratitude, respect, indebtedness and sincere regards to my Supervisor, Prof. (Dr.) Piyush Rai for his excellent supervision, skilled and valuable guidance, stimulating discussion, unfailing support, immense help, and constant encouragement over entire period of my association with him. I am grateful to him for his sincere concern both for academics and personal welfare and parental care throughout the research period that he has extended to me for the successful completion of my research work.

I am privileged to express my deep sense of gratitude, respect and sincere regards to my Co-Supervisor Dr. Suresh Kumar Sharma for his valuable guidance and immense help. I am grateful to him for his sincere concern for academic welfare.

I wish to express my heartfelt thanks to Prof. Piyush Rai, the Head and Dr. S.K. Palei DPGC Convener and my internal RPEC member, of Department of Mining Engineering, Indian Institute of Technology (Banaras Hindu University), Varanasi, for his constant support and blessings.

The support and immense cooperation rendered by the field staff present at Limestone quarry, Chittorgarh, Rajasthan, India, especially Mr. Saurav Kumar.

I am thankful to Dr. Md. Zaheer Khan Yusufzai, my external RPEC member, Department of Mechanical Engineering, IIT (BHU) for giving me valuable suggestions throughout my research period.

I am thankful to Prof. Sushil Bhandari, for his unfailing support during my field visit and, for giving me valuable suggestions throughout my research period.

I am thankful to Dr. Vineeth Balakrishnan, for his valuable guidance, immense help, and rendering special assistance during the final correction phase of thesis.

I am thankful to Ms. Aakriti Raj, for her support and constant encouragement throughout my research period.

I have been highly blessed with a friendly and cheerful group of fellow research scholars. I would like to express my heartfelt gratitude to especially Mr. Prabodh Kumar Kushwaha, Mr. Brijesh Kumar, Nishakar Thakur, Rohit Gautam and Bables Jha, who directly or indirectly supported my research work. Their companionship and lively discussions in and outside the laboratory were great source of inspiration.

I am also grateful to the non-teaching staff members Mr. Ashish Gupta, Mr. Om Prakash Bharti, and Mr. Rajendra Prasad for their support and cooperation during my research work.

Words plunge insufficient to express my regards and deep emotions to my beloved parents for being the source of unconditional love and inspiration to move on the way to my goal of achieving higher education. Their everlasting encouragement, patience, sacrifice and blessings have brought me up to this stage. Parents being earthly God deserve much more than what I can express in words. I would like to offer sincere thanks to my elder brother Mr. Sumeet Shekhar and my elder sister Mrs. Nupur, for their endless support and patience. I cannot forget to pay gratitude to my mother Late Meena Prasad who inspired me always.

I would like to express my gratitude towards the Department of Mining Engineering, IIT (BHU), Varanasi for providing me the necessary facilities for conducting my research work smoothly. I take this occasion to acknowledge the financial assistance provided by Ministry of Human Resource and Development in the form of Teaching Assistantship.

Finally, I bow my head humbly before the almighty God without whose consent and blessings, this work would have been impossible.

(PUNIT PAURUSH)

CONTENTS

CERTIFICATE	i
ACKNOWLEDGMENT	iv
CONTENTS	vi
LIST OF FIGURES	ix
LIST OF TABLES	xii
ABSTRACT	xviii
CHAPTER 1	1
INTRODUCTION	1
1.1 Background and motivation	1
1.2 Statement of problem	9
1.3 Objectives of the study	10
1.4 Organization of the thesis.....	11
CHAPTER 2	13
LITERATURE REVIEW	13
2.1 Introduction.....	13
2.2 Rock breakage by blasting	14
2.3 Assessment of blast performance.....	18
2.3.1 Fragmentation.....	19
2.3.2 Air overpressure	20
2.3.3 Fly rock.....	21
2.3.4 Powder factor	22
2.3.5 Ground vibration	22
2.4 Concept of scaled distance in ground vibrations.....	23
2.5 Powder Factor	24
2.5.1 Factors influencing PF.....	26
2.5.2 Approaches for Prediction of Powder factor	26
2.5.3 Approaches for prediction of ground vibrations due to blasting.....	28
2.6 Recent Approaches for prediction of PPV and PF	35
2.6.1 Statistical approach.....	35
2.6.2 Artificial intelligence approach	37
2.7 Summary of literature review.....	39

CHAPTER 3.....	40
CASE DESCRIPTION.....	40
3.1 Introduction.....	40
3.2 Significant Properties of Nimbahera limestone formation.....	41
3.3 Field description.....	42
3.4 Details of blasting design for the three quarries.....	43
3.4.1 Blasting Pattern details for Quarry ‘A’	43
3.4.2 Blasting Pattern details for Quarry ‘B’	47
3.4.3 Blasting Pattern details for Quarry ‘C’	51
CHAPTER 4.....	54
RESEARCH METHODOLOGY	54
4.1 Outline of Research Methodology	54
4.1.1 Field identification and data collection	54
4.1.2 Measurement of Ground vibrations.....	57
4.1.3 Estimation of Powder Factor (PF).....	58
4.1.4 Statistical and ANN based analysis and validation	59
4.2 Validation and Verification.....	68
4.2.1 Validation with PCA.....	70
4.2.2 Validation with SSE.....	70
4.2.3 Verification by MLP Technique	70
CHAPTER 5.....	71
RESULTS AND DISCUSSION FOR Peak Particle Velocity (PPV).....	71
5.1 Results obtained for all the quarries	71
5.2 Results from PCA technique.....	74
5.2.1 Results obtained for quarry A using PCA	74
5.2.2 Results obtained for quarry B using PCA.....	79
5.2.3 Results obtained for quarry C using PCA.....	84
5.3 Results from SSE technique.....	89
5.3.1 Results obtained for quarry A using SSE	89
5.3.2 Results obtained for quarry B using SSE	92
5.3.3 Results for quarry C using SSE	96
5.4 Results of validation and Verification.....	99
5.4.1 Validation results	99
5.4.2 Verification Results.....	103
5.5 Discussion	112

5.5.1 Identified blasting design parameters affecting PPV by PCA and SSE.....	113
5.6 Overview of the results for all the three quarries.....	116
CHAPTER 6.....	118
RESULTS AND DISCUSSION FOR POWDER FACTOR (PF)	118
6.1 Results of PF estimation.....	118
6.2 Results from PCA.....	119
6.2.1 Results for quarry A using PCA.....	119
6.2.2 Results for quarry B using PCA.....	114
6.2.3 Results for quarry C using PCA.....	129
6.3 Results from SSE technique.....	134
6.3.1 Results for quarry A using SSE.....	134
6.3.2 Results for quarry B using SSE.....	137
6.3.3 Results for quarry C using SSE.....	140
6.4 Results of validation and Verification.....	144
6.4.1 Validation results.....	144
6.4.2 Verification Results.....	147
6.5 Discussion.....	154
6.5.1 Identified blasting design parameters affecting PPV by PCA and SSE.....	155
6.6 Overview of results for PF.....	156
CHAPTER 7.....	158
CONCLUSION	158
7.1 Conclusions.....	158
7.2 Limitations of the future work.....	159
7.3 Suggestions for future work.....	159
REFERENCES	160
APPENDIX.....	187
A.1: Blasting data set of quarry A.....	187
A.2: Blasting data set of quarry B.....	191
A.3: Blasting data set for quarry C.....	194
A.4: Validation data set for quarry A.....	197
A.5: Validation data set for quarry B.....	199
A.6: Validation data set for quarry C.....	193
A.7: Sequential Screenshot of SSE method.....	203
A.8: MLR technique after feeding the blasting design parameters.....	204
LIST OF PUBLICATIONS	205

List of Figures

Figure 2.1: Schematic illustration of processes occurring in the rock around a blast hole, showing formation of crushed zones, fractured zones and fragmented zones	17
Figure 2.2: Blast induced nuisances	17
Figure 2.3: Energy release and distribution of Seismic waves	18
Figure 2.4: Architecture of MLP	38
Figure.3.1: Location of the study quarries	40
Figure 3.2: Representative drilling and firing pattern for quarry A with two rows (not to scale)	44
Figure 3.3: Representative drilling and firing pattern for quarry A with three rows (not to scale)	44
Figure 3.4: Representative blast hole section (diameter 115 mm) (not to scale)	45
Figure 3.5: Representative blast hole section (diameter 152 mm) (not to scale)	45
Figure 3.6: Blasting operation in Quarry ‘A’	46
Figure 3.7: Post-blasting muck profile in Quarry ‘A’	46
Figure 3.8: Representative drilling and firing pattern for quarry B with two rows (not to scale)	47
Figure 3.9: Representative drilling and firing pattern for quarry B with three rows (not to scale)	48
Figure 3.10: Representative blast hole section (diameter 115 mm) (not to scale)	49
Figure 3.11: Representative blast hole section (diameter 152 mm) (not to scale)	49
Figure 3.12: Blasting operation in Quarry ‘B’	50
Figure 3.13: Post-blasting muck profile in Quarry ‘B’	50
Figure 3.14: Representative drilling and firing pattern for quarry C with two rows (not to scale)	51
Figure 3.15: Representative drilling and firing pattern for quarry C with three rows (not to scale)	52

Figure 3.16: Representative drilling and firing pattern for quarry C with four rows (not to scale)	52
Figure 3.17: Representative blast hole section (diameter 150 mm) (not to scale)	53
Figure 3.18: Representative blast hole section (diameter 115 mm) (not to scale)	53
Figure 4.1: A representative graphical output of seismograph record	57
Figure 4.2: Research design	60
Figure 4.3: Block diagram of PCA method	62
Figure 4.4: Results of PCA and Sequential screenshots of PCA method	62
Figure 4.5: Block diagram of SSE method	63
Figure 4.6: Linear regression graph between dependent and independent variable	65
Figure 4.7: Regression curve between PPV and SD	66
Figure 4.8: Scaled conjugate gradient method architecture	68
Figure 4.9: Flowchart of validation	69
Figure 4.10: MLP technique after entering the variable	70
Figure 5.1: Scree plot indicating PC groups for PPV in quarry A	75
Figure 5.2: Scree plot indicating principal component groups for PPV in quarry B	80
Figure 5.3: Scree plot indicating principal component groups for PPV in quarry C	85
Figure 5.4: Comparison of measured and predicted PPV values for quarry A	100
Figure 5.5: Comparison of measured and Predicted PPV Values for quarry B	101
Figure 5.6: Comparison of measured and predicted PPV values for quarry C	102
Figure 5.7: Plot between measured and predicted PPV by ANN (quarry A)	105
Figure 5.8: Independent variables importance chart for PPV (quarry A)	106
Figure 5.9: Plot between measured and predicted PPV by ANN (quarry B)	108
Figure 5.10: Independent variables importance chart for PPV (quarry B)	109
Figure 5.11: Plot between measured and predicted PPV by ANN (quarry C)	111
Figure 5.12: Independent variables importance chart for PPV (quarry C)	112

Figure 6.1: Scree plot indicating principal component groups for PF in quarry A	120
Figure 6.2: Scree plot indicating principal component groups for PF in quarry B	125
Figure 6.3: Scree plot indicating principal component groups for PF in quarry C	130
Figure 6.4: Comparison of measured and Predicted PF Values for quarry A.	144
Figure 6.5: Comparison of measured and predicted PF values for quarry B	145
Figure 6.6: Comparison of measured and predicted PF values for quarry C	146
Figure 6.7: Plot between measured and predicted value of PF by ANN technique (quarry A)	148
Figure 6.8: Independent variables importance chart for PF (quarry A)	149
Figure 6.9: Plot between measured and predicted value of PF by ANN technique (quarry B)	150
Figure 6.10: Independent variable importance chart for PF (Quarry B)	151
Figure 6.11: Plot between measured and predicted value of PF by ANN technique (quarry C)	153
Figure 6.12: Independent variables importance chart for PF (quarry C)	154

List of Tables

Table 1.1: Regulatory limit of ground vibration as per USBM and DIN criteria	07
Table 1.2: Safe blasting limits as per DGMS	07
Table 2.1: Analysis of Blast Design Variables on Ground Vibration	31
Table 3.1: Geological properties of Nimbahera limestone formation	41
Table 3.2: Geotechnical properties of Nimbahera limestone formation	41
Table 3.3: Mineralogical properties of Nimbahera limestone formation	42
Table 3.4: Mineralogical properties of Nimbahera limestone formation	42
Table 4.1: Representative data set of quarry ‘A’	55
Table 4.2: Representative data sets of quarry ‘B’	56
Table 4.3: Representative data sets of quarry ‘C’	56
Table 5.1: Principal descriptive statistics of the blasting data set for prediction of PPV and PF (Quarry A, B and C)	73
Table 5.2: Data matrix explaining variance for the study quarry A (for PPV prediction)	74
Table 5.3: Identification of PCs in the study quarry A (for PPV prediction)	75
Table 5.4: The 7 identified PC groups by PCA for PPV (quarry A)	76
Table 5.5: MLR results for all the identified 16 PCs	76
Table 5.6: Blast design parameters with multi-collinearity (VIF>10) for PPV(quarry A)	77
Table 5.7: Blast design parameters without multi-collinearity (VIF<10) for PPV (quarry A)	77
Table 5.8: Descriptive statistics of 7 parameters for developing predictor Eq. for PPV	78
Table 5.9: MLR based descriptive statistics for the parameters used in Eq. 5.1	78
Table 5.10: Data matrix explaining variance for the study quarry B (for PPV prediction)	79
Table 5.11: Identification of PCs in the study quarry B (for PPV prediction)	80
Table 5.12: The 6 identified PC groups by PCA for PPV (quarry B)	81
Table 5.13: MLR results for all the identified 16 PCs	82
Table 5.14: Blast design parameters with multi-collinearity (VIF >10) for PPV (quarry B)	82

Table 5.15: Blast design parameters without multi-collinearity (VIF <10) for PPV (quarry B)	82
Table 5.16: Descriptive statistics of 9 parameters for developing predictor Eq. for PPV	83
Table 5.17: MLR based descriptive statistics for the parameters used in Eq.5.2	83
Table 5.18: Data matrix explaining variance for the study quarry C (for PPV prediction)	84
Table 5.19: Identification of PCs in the study quarry C (for PPV prediction)	85
Table 5.20: The 7 identified PC groups by PCA for PPV (quarry C)	86
Table 5.21: MLR results for all the identified 15 PCs	86
Table 5.22: Blast design parameters with multi-collinearity (VIF >10) for PPV (quarry C)	87
Table 5.23: Blast design parameters without multi-collinearity (VIF <10) for PPV (quarry C)	87
Table 5.24: Descriptive statistics of 9 parameters for developing predictor eq. for PPV	88
Table 5.25: MLR based descriptive statistics for the parameters used in Eq. 5.3	88
Table 5.26: Correlation matrix with significance values with respect to PPV (quarry A)	89
Table 5.27: MLR results for predicting PPV using the identified 9 parameters	90
Table 5.28: Blast design parameters with multi-collinearity (VIF>10) for PPV (quarry A)	90
Table 5.29: Blast design parameters free from multi-collinearity VIF<10 for PPV (quarry A)	90
Table 5.30: Descriptive statistics of 6 parameters for developing predictor eq. for PPV (quarry A)	91
Table 5.31: MLR based descriptive statistics the parameters used in equation for Eq. 5.4	91
Table 5.32: Summary of models prepared by MLR using SSE for PPV (quarry A)	92
Table 5.33: Correlation matrix with significance values with respect to PPV	92

(quarry B)	
Table 5.34: MLR results for predicting PPV using the identified 13 parameters	93
Table 5.35: Blast design parameters with multi-collinearity (VIF >10) for PPV (quarry B)	93
Table 5.36: Blast design parameters without multi-collinearity (VIF <10) for PPV (quarry B)	94
Table 5.37: Descriptive statistics of 6 parameters for developing predictor eq. for PPV	94
Table 5.38: MLR based descriptive statistics for the parameters used in Eq. 5.5	95
Table 5.39: Summary of models prepared by MLR using SSE for PPV (quarry B)	95
Table 5.40: Correlation matrix with significance values with respect to PPV (quarry C)	96
Table 5.41: MLR for predicting PPV using the identified 12 parameters	97
Table 5.42: Blast design parameters with multi-collinearity (VIF >10) for PPV (quarry C)	97
Table 5.43: Blast design parameters without multi-collinearity (VIF <10) for PPV (quarry C)	97
Table 5.44: Descriptive statistics of 7 parameters for developing predictor eq. for PPV	98
Table 5.45: MLR based descriptive statistics for the parameters used in Eq.5.6	98
Table 5.46: Summary of models prepared by MLR using SSE for PPV (quarry C)	99
Table 5.47: Model summary for PPV using ANN (quarry A)	104
Table 5.48: Model summary for PPV using ANN (quarry B)	107
Table 5.49: Model Summary foe PPV using ANN (quarry C)	110
Table 5.50: Results at a glance for PPV (Quarry A, B and C)	117
Table 6.1: Discrepancy in theoretical and actual PF	118
Table 6.2: Data matrix explaining variance for the study quarry A (for PF prediction)	119

Table 6.3: Identification of PCs in the study quarry A for PF	120
Table 6.4: The 6 identified PC groups by PCA for PF (quarry A)	121
Table 6.5: MLR results for the identified 14 PCs	121
Table 6.6: Blast design parameters with multi-collinearity (VIF>10) for PF (quarry A)	122
Table 6.7: Blast design parameters with multi-collinearity (VIF<10) for PF (quarry A)	122
Table 6.8: Descriptive statistics of 6 parameters for developing predictor eq. for PF	123
Table 6.9: MLR based descriptive statistics for the parameters used in Eq. 6.1	123
Table 6.10: Data matrix explaining variance for the study quarry B (for PF prediction)	124
Table 6.11: Identification of PCs in study quarry B for PF	125
Table 6.12: The 6 identified PC groups by PCA for PF (quarry B)	126
Table 6.13: MLR results for the identified 15 PCs	126
Table 6.14: Blast design parameters with multi-collinearity (VIF >10) for PF (quarry B)	127
Table 6.15: Blast design parameters without multi-collinearity (VIF <10) for PF (quarry B)	127
Table 6.16: Descriptive statistics of 9 parameters for developing predictor eq. for PF	128
Table 6.17: MLR based descriptive statistics for the parameters used in Eq. 6.2	128
Table 6.18: Data matrix explaining variance for the study quarry C (for PF prediction)	129
Table 6.19: Identification of PCs in the study quarry C for PF	130
Table 6.20: The 7 identified PC groups by PCA for PF (quarry C)	131
Table 6.21: MLR results for all the identified 12 PCs	131
Table 6.22: Blast design parameters with multi-collinearity (VIF >10) for PF (quarry C)	132
Table 6.23: Blast design parameters without multi-collinearity (VIF <10) for PF (quarry C)	132
Table 6.24: Descriptive statistics of 8 parameters for developing predictor eq.	133

for PF	
Table 6.25: MLR based descriptive statistics for the parameters used in Eq. 6.3	133
Table 6.26: Correlation matrix with significance values with respect to PF (quarry A)	134
Table 6.27: MLR results for predicting PF using the identified 9 parameters	134
Table 6.28: Blast design parameters with multi-collinearity (VIF >10) for PF (quarry A)	135
Table 6.29: Blast design parameters without multi-collinearity (VIF <10) for PF (quarry A)	135
Table 6.30: Descriptive statistics of 4 parameters for developing predictor eq. for PF	136
Table 6.31: MLR based descriptive statistics for the parameters used in the Eq. 6.4	136
Table 6.32: Summary of models prepared by MLR using SSE for PF (quarry A)	137
Table 6.33: Correlation matrix with significance values with respect to PF (quarry B)	137
Table 6.34: MLR results for predicting PF using the identified 11 parameters	138
Table 6.35: Blast design parameters with multi-collinearity (VIF >10) for PF (quarry B)	138
Table 6.36: Blast design parameters without multi-collinearity (VIF <10) for PF (quarry B)	138
Table 6.37: Descriptive statistics of 8 parameters for developing predictor eq. for PF	139
Table 6.38: MLR based descriptive statistics for the parameters used in Eq. 6.5	139
Table 6.39: Summary of models prepared by MLR using SSE for PF (quarry B)	140
Table 6.40: Correlation matrix with significance values with respect to PF (quarry C)	140
Table 6.41: MLR for predicting PF using the identified 8 parameters	141
Table 6.42: Blast design parameters with multi-collinearity (VIF <10) for	141

PF (quarry C)	
Table 6.43: Blast design parameters without multi-collinearity (VIF >10) for PF (quarry C)	142
Table 6.44: Descriptive statistics of 6 parameters for developing predictor eq. for PF	142
Table 6.45: MLR based descriptive statistics for the parameters used in Eq. 6.6	143
Table 6.46: Summary of models prepared by MLR using SSE for PF (quarry C)	143
Table 6.47: Model Summary for PF using ANN (quarry A)	148
Table 6.48: Model Summary of PF using ANN (quarry B)	150
Table 6.49: Model Summary of PF using ANN (quarry C)	152
Table 6.50: Results at a glance for PF (Quarry A, B and C)	157

ABSTRACT

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. Further the impact of efficacy is also assessed by evaluation of powder factor. The powder factor impacts secondary breakage and the diggability of the excavators. The thrust area of the research has been to identify the blasting design and explosive parameters affecting peak particle velocity and powder factor for controlling the blasting nuisances. Many studies have been conducted earlier using only a limited number of controllable blast design parameters affecting peak particle velocity and powder Factor. However, only a limited number of studies have been carried out including a host of significant controllable blast design parameters.

In light of this, the present work contributes by developing a model using principal component analysis and step-wise selection and elimination statistical technique. The developed equation is validated within the statistical domain and the verified by employing multi-layer perceptron (artificial neural network) technique.

To comply with the objectives of research work, the sites for experimental blasts were selected considering almost similar geo-mining conditions. A total of 285 number of blasts (from three quarries) were recorded. Accordingly, the complete dataset comprising of 97 blast round in quarry 'A', 88 blast round in quarry 'B' and 100 blast round in quarry 'C' were produced for analysis. All the datasets recorded in terms of blasting design parameters and subsequently, the value of peak particle velocity is recorded and the value of powder factor were measured. In all the quarries, the 75% of datasets were used for development of the model and 25% were used for the validation of the developed model. Further, to develop the statistical models in the form of equation for powder factor and peak

particle velocity, principal component analysis and stepwise selection and elimination followed by multi-variate linear regression technique have been used. The developed equations have been validated on another dataset and further verification has been carried out.

On validation within the statistical domain, for peak particle velocity and powder factor in all the quarries, the predicted values of peak particle velocity and powder factor are lying closer to the measured values. But, the values predicted by principal component analysis reveals the most accurate values of peak particle velocity and powder factor in comparison to stepwise selection and elimination and square root equation (in case of peak particle velocity only).

Apart from the statistical domain, Multilayer Perceptron (ANN) technique has also been used to verify the equation developed by both principal component analysis and stepwise selection and elimination tools and also to determine the correlation between the blasting design parameters with peak particle velocity and powder factor. It is found that the value of R^2 derived by artificial neural network is much higher than the values of R^2 derived by both principal component analysis and stepwise selection and elimination. This indicates that the accuracy of artificial neural network in predicting peak particle velocity and powder factor is very much satisfactory in comparison to principal component analysis and stepwise selection and elimination, and doubly validate the authenticity of equation developed by principal component analysis and stepwise selection and elimination in predicting the peak particle velocity and powder factor. However, principal component analysis and stepwise selection and elimination have also indicated excellent value of R^2 vis-à-vis better authenticity of the model to predict both peak particle velocity and powder factor.