CHAPTER 4

RESEARCH METHODOLOGY

4.1 Outline of Research Methodology

The present research work comprises of nine stages, viz,, Identification and selection of suitable sites for conduct and recording of blasting in the field scale quarries, recording of peak particle velocity (PPV), estimation of powder factor (PF), application of PCA technique to identify the salient blasting design parameters affecting the PPV and PF, application of SSE technique to identify the salient blasting design parameters affecting the PPV and PF, application multi-variate linear regression (MLR) technique to develop the best fit statistical models for the deployed PCA and SSE techniques, validation of the models developed by statistical techniques, Comparison of the developed models for PPV with the predicted values using USBM square root equation, and verification by AI technique (outside the statistical domain) using multi-layer perceptron based Artificial neural network (ANN) technique to validate the authenticity of prediction and validation of the results obtained by statistical techniques (PCA, SSE & MLR).

The step-by-step description of each stage follows as below:

4.1.1 Field identification and data collection

To accomplish the stated objective of the research work, blast rounds were carried out at three different open pit limestone quarries of Rajasthan. The quarries were selected by considering 3 quarries from a group of quarries that possessed similar geo-mining conditions with insignificant geological anomalies among them. Therefore, the field studies were performed in these quarries. A total of 285 number of blast rounds (from three quarries) were recorded for the purpose of the study without interfering the blasting design. Out of these 285 study blasts, 75% (215 blasts) were used for development of model in the form of equation and 25% (70 blasts) blasts were used for validation of the developed equation.

Fifteen representative datasets of the blastrounds as conducted and recorded in the quarry A, quarry B and quarry C are tabulated in Tables 4.1, 4.2 and 4.3 respectively to provide a cursory insight of blasting design parameters. Complete blasting data set, which have been used for development of equation for Quarry A (79), quarry B (65) and quarry C (75) are provided in Appendix- A.1, A.2 & A.3 respectively.

Table 4.1: Representative data set of quarry 'A'

Blast_I	B	D	S	H	T	CCL	S/B	T/B	H/B	T/CC	N_r	N_h	Q_e	Di	CPD	HD	RD	Vr	Th.PF	Act.PF	SD	PPV
B1	4.0	150	5.0	10	4	6	1.3	1.0	2.5	0.67	2	13	946.4	280	84.8	42	65	4800.0	0.22	0.20	30.4	3.40
B2	4.5	150	6.0	10	3.8	6.2	1.3	0.8	2.2	0.61	3	25	1174.5	350	88.6	17	25	10800.0	5.56	0.18	37.2	2.90
B3	4.3	150	5.5	10	3.5	6.5	1.3	0.8	2.3	0.54	2	15	833.6	300	90.5	42	65	6385.5	5.56	0.18	31.5	2.50
B4	3.4	110	4.7	10	3.7	6.3	1.4	1.1	2.9	0.59	2	16	992.2	200	47.9	25	65	4314.6	0.22	0.19	28.9	4.80
B5	3.2	110	4.5	10	4.2	5.8	1.4	1.3	3.1	0.72	2	22	1236.4	350	45.2	42	65	4752.0	0.21	0.19	52.1	1.40
B6	4.5	150	6.0	10	3.6	6.4	1.3	0.8	2.2	0.56	2	22	813.4	320	88.5	42	65	8910.0	0.15	0.13	34.0	1.60
B7	4.3	150	5.5	10	4.2	5.8	1.3	1.0	2.3	0.72	2	14	994.4	300	78.8	42	65	5676.0	0.16	0.14	33.8	2.90
B8	3.0	110	4.5	10	3.5	6.5	1.5	1.2	3.3	0.54	2	22	968.8	210	49.4	25	65	4455.0	0.22	0.20	29.9	4.20
B9	4.5	150	6.0	11	4.9	6.1	1.3	1.1	2.4	0.80	2	14	1054.5	270	92.0	42	65	7128.0	0.16	0.14	28.1	3.40
B10	4.0	150	5.5	10	3.8	6.2	1.4	1.0	2.5	0.61	2	15	782.4	320	92.2	42	65	5940.0	5.56	0.18	33.3	2.76
B11	4.3	150	6.0	10	4.2	5.8	1.4	1.0	2.3	0.72	2	12	844.5	300	89.4	25	65	5418.0	0.15	0.14	31.7	2.30
B12	4.1	150	5.5	10	4.3	5.7	1.3	1.0	2.4	0.75	2	15	718.9	400	84.7	42	65	6088.5	0.16	0.14	43.5	0.70
B13	3.5	110	5.0	10	3.5	6.5	1.4	1.0	2.9	0.54	2	13	980.8	220	50.6	25	65	4200.0	0.18	0.17	30.9	3.50
B14	4.5	150	6.0	10	4.1	5.9	1.3	0.9	2.2	0.69	2	16	1650.0	250	87.7	42	65	7290.0	0.15	0.13	26.7	4.20
B15	3.2	110	4.8	10	3.9	6.1	1.5	1.2	3.1	0.64	4	33	1188.8	310	47.5	42	65	7680.0	4.76	0.21	45.0	2.48

B= Burden (m) D= Hole diameter (m) S= Spacing (m) H= Bench height (m) T= Stemming length (m)

CCL= Column charge length (m) S/B= Spacing/Burden ratio T/B= Stemming/Burden ratio

H/B= Height/Burden ratio T/CCL=Stemming/Column charge length ratio Nr= Number of rows

Nh= Number of holes Qe= Total amount of explosive Di= Distance of measuring point from the blast round (m)

CPD= Charge per delay (Kg) HD=Inter hole delay (ms) RD= Inter row delay (ms)

Vr= Volume of rock broken (m^3or t)   Th.PF= Theoretical powder factor(Kg/t)
Act.PF= Actual powder factor (KG/t)

SD= Scaled distance ($m/Kg^{0.5}$)   PPV= Peak Particle Velocity (mm/s)

Table 4.2: Representative data sets of quarry 'B'

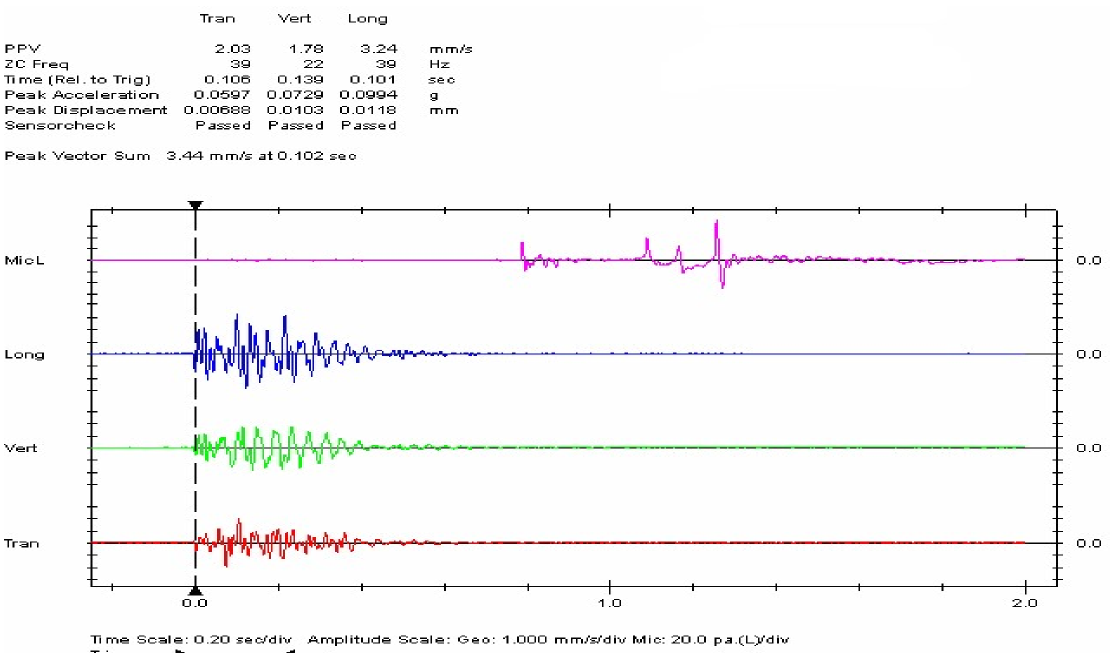
Blast_ID	B	D	S	H	T	CCL	S/B	T/B	H/B	T/CCL	N_r	N_h	Qe	CPD	Di	HD	RD	Vr	Th. PF	Act. PF	SD	PPV
B1	3.0	115	4.5	10.0	3.6	6.4	1.50	1.20	3.33	0.56	2	17	665.0	46.0	140	17	42	1575.0	0.18	0.16	20.6	3.87
B2	3.5	115	5.0	10.5	3.4	7.1	1.43	0.97	3.00	0.48	2	18	742.5	47.6	160	17	42	5512.5	0.14	0.13	23.2	2.46
B3	3.5	115	5.0	9.0	3.3	5.7	1.43	0.95	2.57	0.59	3	25	913.0	49.2	180	17	25	6300.0	0.15	0.14	25.7	1.63
B4	3.5	115	4.8	9.0	3.4	5.7	1.37	0.96	2.57	0.59	2	15	547.8	48.1	150	17	25	4082.4	0.16	0.13	21.6	1.27
B5	3.0	115	4.5	9.5	3.3	6.2	1.50	1.09	3.17	0.52	3	24	1011.6	52.2	210	17	25	4617.0	0.23	0.22	29.1	1.12
B6	3.5	110	4.0	10.0	4.2	5.9	1.14	1.19	2.86	0.71	3	25	956.3	46.3	150	17	25	5600.0	0.18	0.17	22.0	2.94
B7	3.5	115	5.0	10.0	4.1	6.0	1.43	1.16	2.86	0.68	2	18	704.7	52.3	200	17	42	5250.0	0.15	0.13	27.7	3.14
B8	3.5	115	5.0	9.0	3.0	6.0	1.43	0.87	2.57	0.51	2	16	631.2	50.7	240	17	25	4252.5	0.16	0.15	33.7	2.41
B9	3.5	115	5.0	9.5	3.9	5.6	1.43	1.11	2.71	0.69	2	18	632.2	47.8	230	17	42	4987.5	0.15	0.13	33.3	1.58
B10	3.0	115	4.5	10.0	3.5	6.5	1.50	1.17	3.33	0.54	4	33	1158.6	47.5	260	17	42	6750.0	0.18	0.17	37.7	1.65
B11	3.5	110	4.8	10.5	3.4	7.1	1.37	0.97	3.00	0.48	2	15	676.8	47.3	190	17	25	4762.8	0.15	0.14	27.6	1.59
B12	3.0	110	4.4	10.0	3.0	7.0	1.47	1.00	3.33	0.43	3	26	929.0	49.3	200	17	42	5280.0	0.19	0.18	28.5	2.59
B13	3.5	110	5.0	9.0	3.4	5.6	1.43	0.98	2.57	0.61	3	26	890.5	43.5	300	17	25	6300.0	0.18	0.16	45.5	0.89
B14	3.0	110	5.0	10.0	3.2	6.8	1.67	1.07	3.33	0.47	2	17	614.0	46.0	250	17	25	4500.0	0.16	0.14	36.8	2.03
B15	3.5	115	5.0	10.0	3.3	6.8	1.43	0.93	2.86	0.48	2	16	660.0	55.3	290	17	25	4725.0	0.16	0.14	39.0	0.83

Table 4.3: Representative data sets of quarry 'C'

Blast_ID	B	D	S	H	T	CCL	S/B	T/B	H/B	T/CCL	N_r	N_h	Qe	Di	CPD	HD	RD	Vr	Th. PF	Act.PF	SD	PPV
B1	3.0	115	4.0	10.0	3.9	6.1	1.33	1.30	3.33	0.64	3	28	1449.8	450	61.3	17	42	4800.0	0.30	0.28	57.5	1.9
B2	3.5	115	4.5	11.0	4.4	6.6	1.29	1.26	3.14	0.67	2	15	871.8	345	63.0	17	42	4677.8	0.19	0.18	43.5	1
B3	3.5	115	4.5	10.0	4.5	5.5	1.29	1.29	2.86	0.82	3	29	1428.3	250	55.2	17	25	6930.0	0.21	0.20	33.7	3.5
B4	3.0	115	4.0	10.0	3.8	6.2	1.33	1.27	3.33	0.61	4	36	1885	420	56.3	17	42	6000.0	0.31	3.18	56.0	1.1
B5	3.0	115	4.0	10.0	3.9	6.1	1.33	1.30	3.33	0.64	2	17	803.25	300	49.3	17	42	3600.0	0.22	4.48	42.7	1.3
B6	3.5	115	4.5	10.0	4.2	5.8	1.29	1.20	2.86	0.72	3	25	1266	500	55.2	17	25	6300.0	0.20	4.98	67.3	1.1
B7	3.5	115	4.6	10.0	3.9	6.1	1.31	1.11	2.86	0.64	4	36	1913	250	55.0	17	25	8050.0	0.24	0.22	33.7	3.7
B8	3.7	115	5.0	10.0	4.0	6.0	1.35	1.08	2.70	0.67	3	27	1412.6	350	61.8	17	25	7400.0	0.19	5.24	44.5	2.1
B9	3.5	115	4.5	10.0	4.5	5.5	1.29	1.29	2.86	0.82	3	26	1280.5	320	51.3	17	25	6300.0	0.20	0.18	44.7	1.9
B10	3.5	115	4.5	10.5	4.1	6.4	1.29	1.17	3.00	0.64	3	27	1545.8	360	65.3	17	25	6615.0	0.23	4.28	44.6	2.1
B11	4.0	150	5.0	11.0	4.5	6.5	1.25	1.13	2.75	0.69	2	15	1113.8	450	91.3	17	42	5940.0	0.19	0.17	47.1	0.8
B12	3.0	115	4.0	10.5	3.9	6.6	1.33	1.30	3.50	0.59	4	37	2009.5	300	56.2	17	25	6300.0	0.32	0.29	40.0	3.8
B13	3.0	115	4.0	10.6	3.6	7.0	1.33	1.20	3.53	0.51	2	18	1010.7	250	59.4	17	25	3816.0	0.26	3.78	32.4	2.3
B14	3.5	115	4.5	11.0	4.3	6.7	1.29	1.23	3.14	0.64	2	18	1023.3	350	61.2	17	42	5197.5	0.20	0.18	44.8	1.2
B15	3.0	115	4.0	11.0	3.8	7.2	1.33	1.27	3.67	0.53	4	37	2007.6	400	55.2	17	25	7260.0	0.30	0.28	53.8	2.9

4.1.2 Measurement of Ground vibrations

The ground vibrations were measured in terms of PPV. For the measurement of PPV in the study quarries, Seismograph was used. It was placed at different distances from the blasting site and the ground vibrations were recorded in terms of PPV. The seismograph consisted of tri-axial geophone with transducer, placed at the ground surface facing the direction of blast for measuring the ground vibration in terms of PPV, the graphical output of seismograph is illustrated in Figure 4.1. For all blast rounds, the seismograph has been placed at distances 100-400m from the blasting face. The seismograph measures the ground vibration in terms of PPV in all the three direction. The range of PPV measurement of the used seismograph was 0 – 10 in/s (0-254 mm/s), its resolution was 0.005 in/s, its measuring frequency range was 2 – 400 Hz and its accuracy was found as ±3%.



```
                          Tran      Vert      Long

PPV                       2.03      1.78      3.24    mm/s
ZC Freq                     39        22        39    Hz
Time (Rel. to Trig)      0.106     0.139     0.101    sec
Peak Acceleration       0.0597    0.0729    0.0994    g
Peak Displacement      0.00688    0.0103    0.0118    mm
Sensorcheck             Passed    Passed    Passed

Peak Vector Sum   3.44 mm/s at 0.102 sec
```

```
Time Scale: 0.20 sec/div   Amplitude Scale: Geo: 1.000 mm/s/div Mic: 20.0 pa.(L)/div
```

Figure 4.1: A representative graphical output of seismograph record

4.1.3 Estimation of Powder Factor (PF)

Theoretical powder factor can be readily determined by use of mathematical equation. However, the challenging task is to determine the actual or practical values of powder factor in the field scale. As such the description follows:

(i) Theoretical powder factor estimation method

For the establishment of theoretical PF in the limestone quarries, the volume of rock blasted and the total amount of explosive is required.

The volume of rock was calculated as below in Eq 4.1:

$$V = B \times S \times H \times N \tag{4.1}$$

Where, V= tonne of limestone (t), B=Burden (m), S= Spacing (m), H= Bench height (m), N=No. of Rows

The consumption of explosive per blast was computed from the field data collected on total Q of explosive charge in each blast round. The amount of explosive (Q) was measured in Kg, and after that PF was calculated as given in Eq.4.2

$$PF = \frac{Q}{V} \tag{4.2}$$

Where, PF=Powder factor (Kg/m^3), Q= Total amount of explosive (Kg), V= cubic meter ($m^{3)}$

(ii) Actual powder factor estimation method

The powder factor was precisely estimated by properly observing and recording the total number of trucks loaded during the complete excavation of the muck pile. The total number of truck trips on individual muck pile was carefully counted and converted into equivalent tonnage of limestone removed from the muck pile by giving

proper consideration to truck factor, which, in turn, was calibrated by the conveyor weighing machine system. The boulders, which could not be handled by the excavator from the muck pile, were separated at the bench, and, were not included in the tonnage computations. However, blasting design were improved in subsequent blasts and boulders were reduced significantly by the quarry management. Despite this it was observed that the boulder free blastround is almost impossible. The total quantity of explosive actually loaded in the blast round was registered in order to express the powder factor in terms of Kg/t of limestone broken from the blast rounds.

It may be appropriate to mention here that the practical powder factor values, as determined above were doubly verified from the field surveyor's records. The two values matched very closely for quarries 'A', 'B' and 'C'.

4.1.4 Statistical and ANN based analysis and validation

The point numbers (*i*) to (*v*) as mentioned in section 4.1.4 and are explained through research design illustrated as flow chart in Figure 4.2 followed by its stepwise explanation.

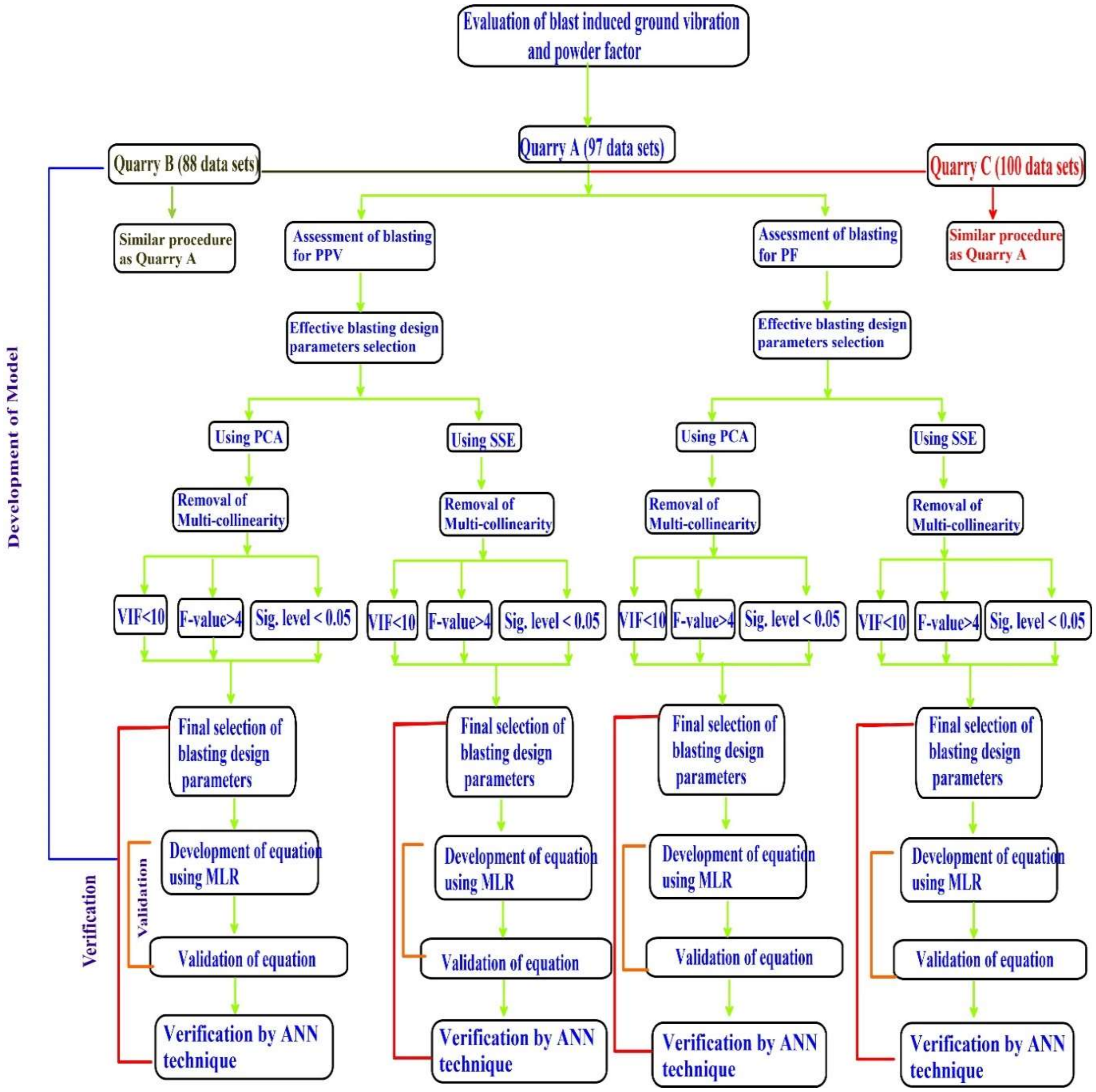


Figure 4.2: Research design

The research design includes the conduct of real-time blasting and the measurement of PPV and powder factor (PF) values. All the blasting rounds were carried out in limestone quarries with almost identical geological and geo-mining parameters without any significant geological anomaly in the rock. Further the explosive, firing pattern and initiation systems were also identical in the quarries. The blasting rounds were thus carried out for the evaluation of blast induced ground vibration (in terms of PPV) and powder factor (PF).

A number of 97 datasets were recorded in quarry A, 88 data sets were recorded in quarry B and 100 data sets were in quarry C. For each blast round the data of salient blast design parameters were documented, the corresponding values of PPV and PF were measured for each blast round. 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 PPV is recorded and the value of PF were measured. In all the quarries, the 75% of datasets were used for development of the equation and 25% were used for the validation of the developed equation.

(i) Application of principal component analysis (PCA) technique

To select the significant blasting design parameters (from the documented blasting design parameters from field data) affecting the PPV and PF, the PCA statistical technique was used. The PCA identified the blasting design parameters in the form of principal components. The principal components have been selected on the basis of eigen value (when eigen value>1) (Figure 4.1). Subsequently, from the principal components group, only those blasting design parameters were selected which offered high order of correlations with PPV and PF.

After the identification of blasting design parameters, it was found that some of the parameters was having multi-collinearity. To remove the multi-collinearity, a term called Variance inflation factor (VIF) was deployed. The Variance Inflation Factor (VIF) was used to measure the intensity of the correlation of the predictor variables (Polhemus, 2005). VIF greater than 10 suggests multi-collinearity among independent variables (Wang et al., 2016). Therefore, to remove the multi-collinearity, we further selected only those independent variables (blasting design parameters) which revealed VIF values of less than 10.

The screenshots of the PCA technique, as explained in the preceding passages is sequentially revealed in block diagram (Figure 4.3) and series of screenshots in (Figure 4.4).

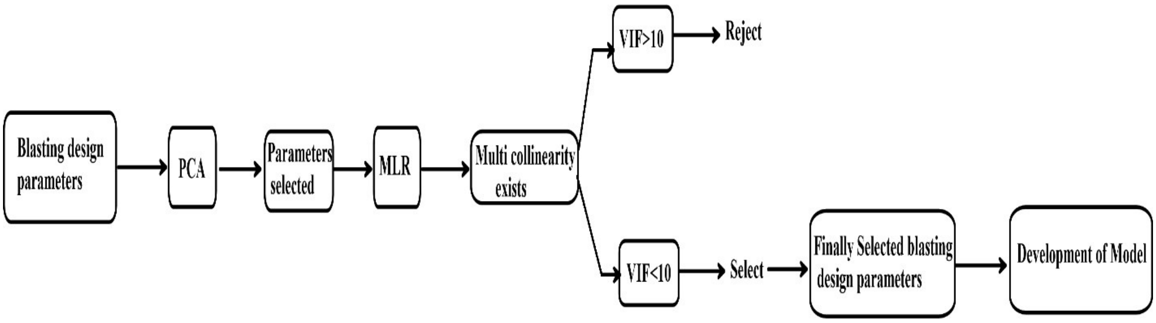
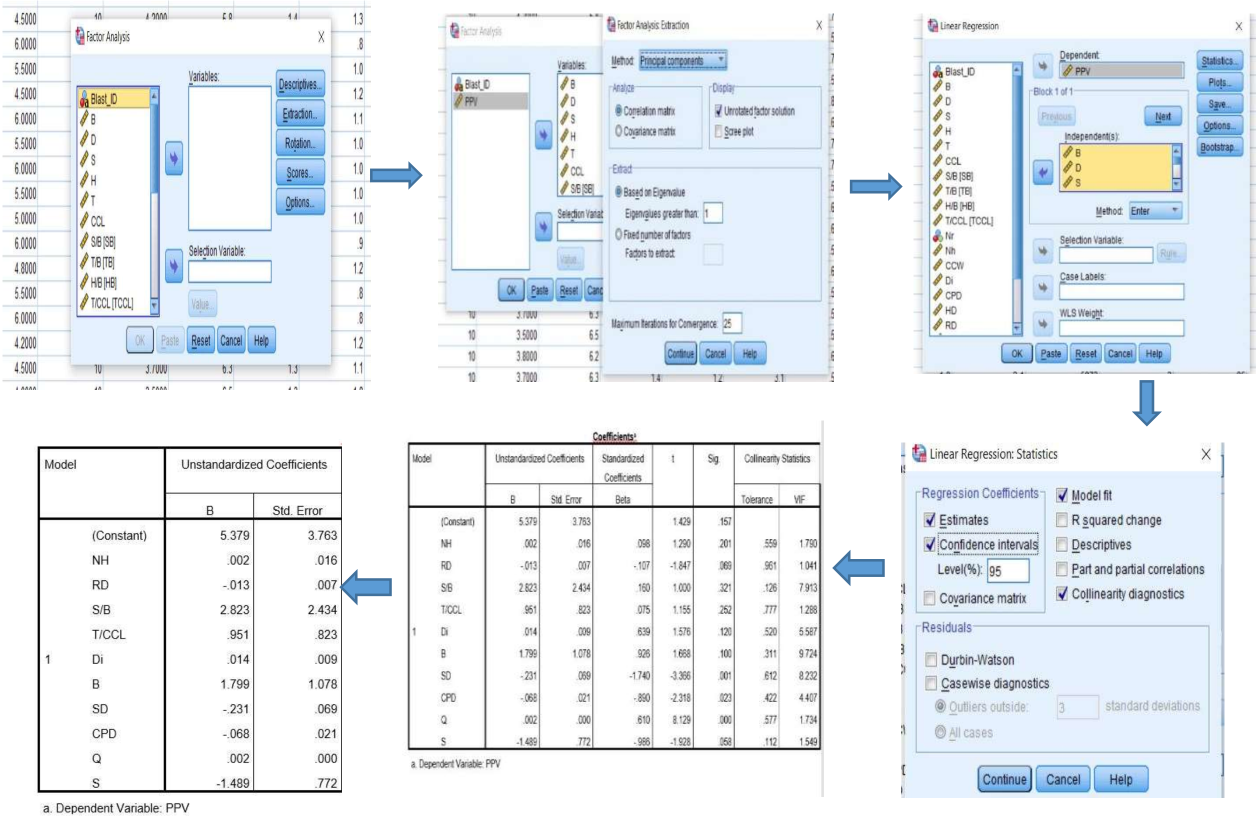


Figure 4.3: Block diagram of PCA method



Linear Regression: Statistics

Regression Coefficients
☑ Estimates
☑ Confidence intervals
Level(%): 95
☐ Covariance matrix
☑ Model fit
☐ R squared change
☐ Descriptives
☐ Part and partial correlations
☑ Collinearity diagnostics

Residuals
☐ Durbin-Watson
☐ Casewise diagnostics
○ Outliers outside: 3 standard deviations
○ All cases

Continue Cancel Help

Coefficients^a

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	5.379	3.763		1.429	.157		
	NH	.002	.016	.098	1.290	.201	.559	1.790
	RD	-.013	.007	-.107	-1.847	.069	.961	1.041
	S/B	2.823	2.434	.160	1.000	.321	.126	7.913
	T/CCL	.951	.823	.075	1.155	.252	.777	1.288
	Di	.014	.009	.639	1.576	.120	.520	5.587
	B	1.799	1.078	.926	1.668	.100	.311	9.724
	SD	-.231	.069	-1.740	-3.366	.001	.612	8.232
	CPD	-.068	.021	-.890	-2.318	.023	.422	4.407
	Q	.002	.000	.610	8.129	.000	.577	1.734
	S	-1.489	.772	-.986	-1.928	.058	.112	1.549

a. Dependent Variable: PPV

Model		Unstandardized Coefficients	
		B	Std. Error
1	(Constant)	5.379	3.763
	NH	.002	.016
	RD	-.013	.007
	S/B	2.823	2.434
	T/CCL	.951	.823
	Di	.014	.009
	B	1.799	1.078
	SD	-.231	.069
	CPD	-.068	.021
	Q	.002	.000
	S	-1.489	.772

a. Dependent Variable: PPV

Figure 4.4: Results of PCA and Sequential screenshots of PCA method

(ii) Application of stepwise selection and elimination (SSE) technique

Stepwise selection and elimination (SSE) is a well-known technique that uses statistical significance to select the explanatory variables (blast design parameters in this case) to be used in multi-variate regression model. The selection and elimination of blasting design parameters affecting the PPV and PF is based on the Pearson's correlation coefficient and significance value of the input parameters. On the basis of Pearson's correlation coefficient, only those parameters, which have significance level < 0.05 were selected and the parameters which had significance level > 0.05 were considered insignificant and, thereby rejected.

The screenshots of the SSE technique, as explained in the preceding passages is sequentially revealed in block diagram (Figure 4.5) and series of screenshots in A.7 of the appendix.

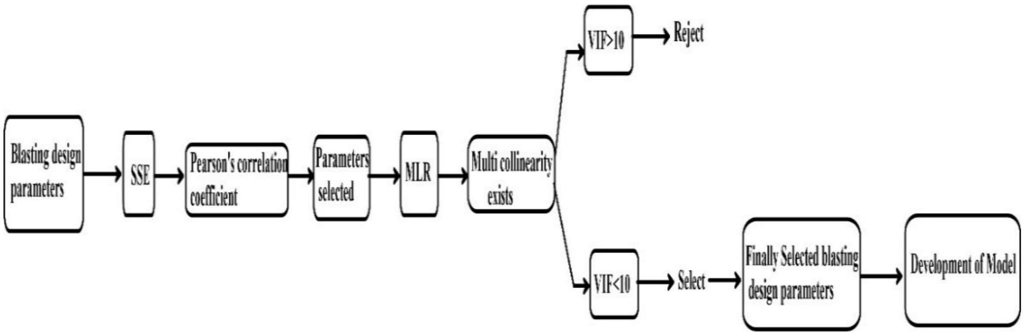


Figure 4.5: Block diagram of SSE method.

In the present work the statistical tools have been used to identify the independent variables to access their impact on dependent variables. Both PCA and SSE statistical methods has been used to accomplishing the aforesaid.

PCA and SSE techniques are suitable for the large number of datasets as well as large number of variables. We have taken 285 blasting data sets and 19 variables to carry out this work. For such large number of datasets, the PCA and SSE has the better ability to predict the output. So, it is beneficial for us to use PCA and SSE techniques.

The PCA and SSE has many advantages over other statistical methods, such as:

i. PCA and SSE techniques are considered as maximum variance technique and hence it eliminates the variables which has low variance.

ii. It also decreases the risk that may be generated in large data sets, which are sometimes responsible for the overfitting of data.

iii. In light of the above two points, it is quite obvious that PCA and SSE techniques are much more advanced and superior in statistical analysis in comparison to the conventional and even other contemporary techniques.

iv. Many researchers has used these techniques to provide good statistical results (Efroymso, 1960; Hoteling, 1993; Jackson, 1998; Krabbe, 2016 and Smith, 2018).

(iii) Development of equation by multi-variate linear regression (MLR) technique

The selected parameters extracted from the PCA and SSE were used to formulate the equations for the prediction of PPV and PF using MLR technique (A.8 of appendix).

On applying MLR, the multi-collinearity among input variables needs to be identified and removed. To remove the multi-collinearity, Variance inflation factor (VIF) is used. One more parameter, namely, the (F-ratio) indicates the reliability of obtained results.

If F-ratio increases, results become more trustworthy. So, the technique is based on selecting the equation with highest value of F-ratio.

After final selection of blasting design parameters, application of the MLR technique develop the equation for both PCA and SSE. MLR technique has been used to establish

the connection between input and output parameters for developing the equation, as per Eq.4.3, which is given below:

$$\bar{Y} = a + b_1X_1 + b_2X_2 + \cdots \dots\dots\dots\dots\dots\dots\dots\dots + b_n X_n \tag{4.3}$$

Where,

$\bar{Y}$ is predicted value of Y, a is the intercept and, b (slope) is the partial regression coefficient (as shown in Figure 4.6).

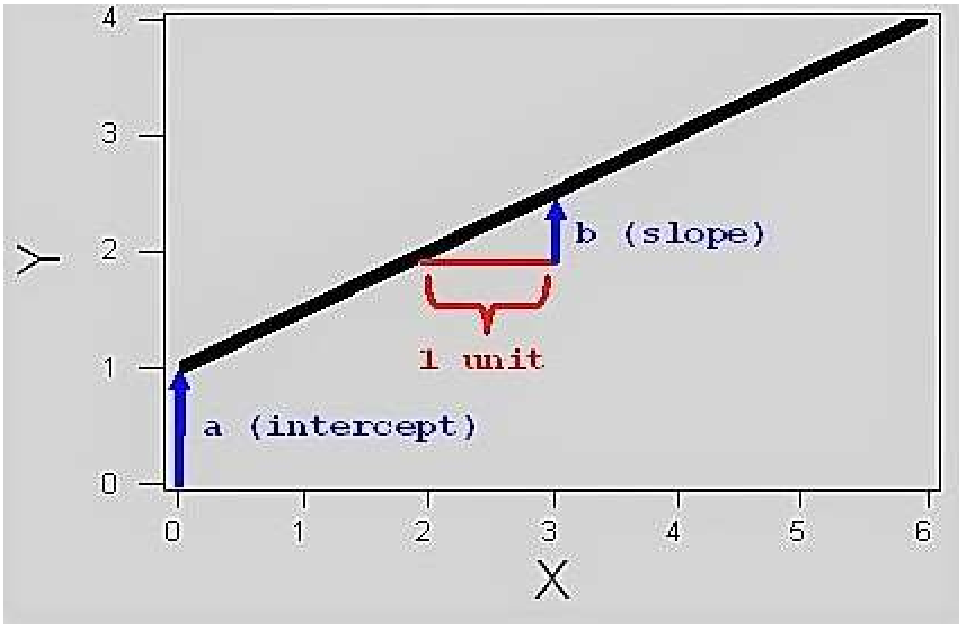


Figure 4.6: Linear regression graph between dependent and independent variable

(iv) USBM square root equation

The values of PPV has been calculated with the help of USBM equation, as given in Eq.4.4 and 4.5.

$$PPV = \alpha(SD)^{-\beta} \tag{4.4}$$

and,

$$SD = \frac{D}{Q^{0.5}} \tag{4.5}$$

where, SD = scaled distance $(\frac{m}{kg^{0.5}})$, D = radial distance of measuring station from blasting site (m), Q = amount of explosive (kg) , a = constant (0.5), α and β are site constants.

α and β were determined by multiple regression analysis. Figure 4.7, graphically represented the PPV vs SD relationship.

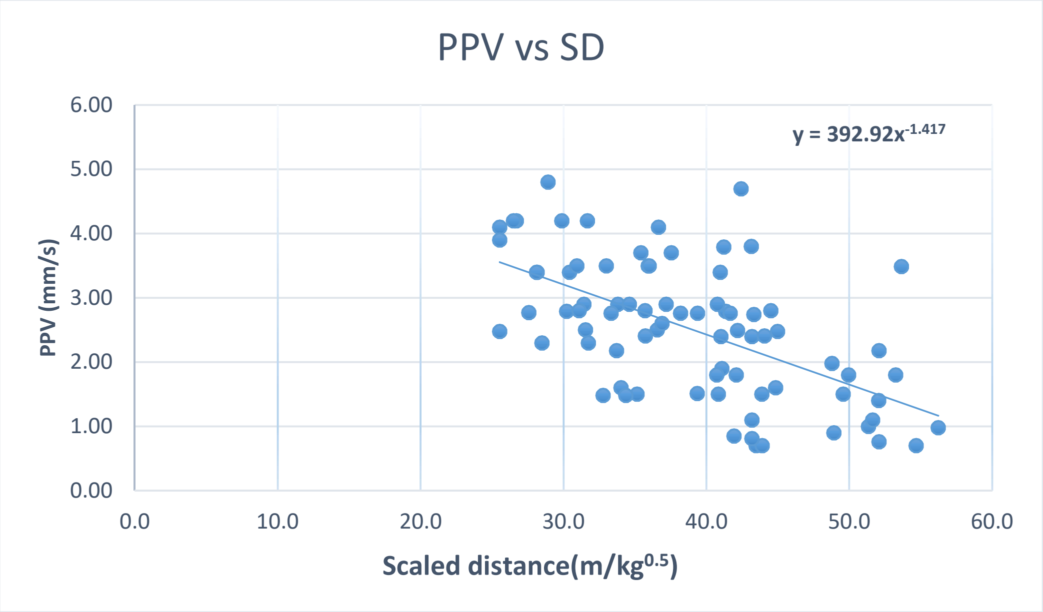


Figure 4.7: Regression curve between PPV and SD

In Figure 4.9 has been indicated in the equation, PPV = 392.92(SD)$^{-1.417}$, where, α = 392.92 and β = -1.417. The value of R^2 has been also predicted by the curve, which has been found to be 0.74 in this case.

As such, the calculated value of PPV has been used to compare the values predicted by the equations developed using PCA and SSE.

(v) Application of ANN technique

The Multilayer Perceptron (MLP) neural network Module was used to build the neural architecture and test its accuracy. MLP neural networks were trained using a back-propagation algorithm to update weights to reduce the error function. Out of total number of conducted blasting datasets, 70 % of datasets were used for training and 30% of the datasets were assigned for testing. The training dataset were used to find the weights and build the model. The testing dataset were used to find errors to prevent overtraining.

For batch training of the ANN, the scaled conjugate gradient method (Figure 4.8), which is an iterative approach for solving linear equations has been used. When this algorithm was used to train a multilayer perceptron network, it was found to be more effective. Before each iteration, all training datasets were collected and synaptic weights were updated. The algorithm therefore sought the lowest global error surface by minimizing the total error in the previous iteration.

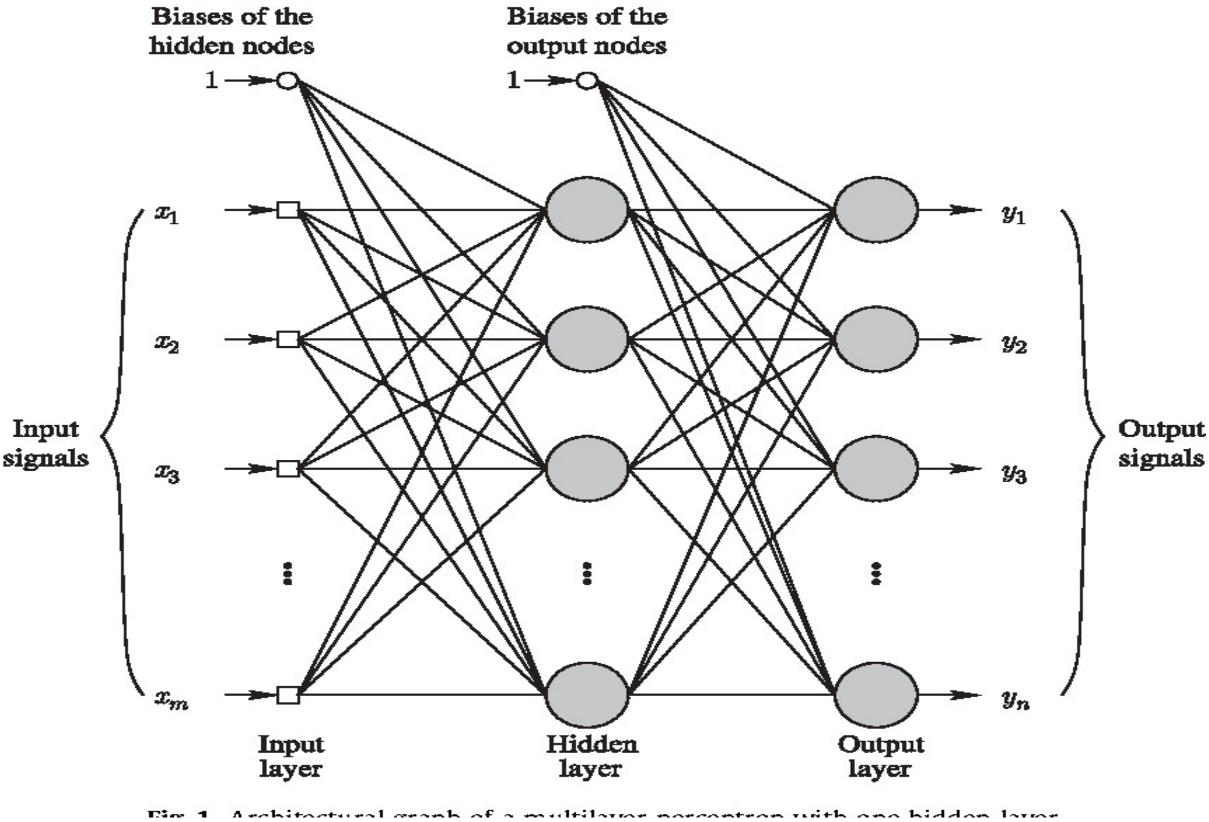


Figure 4.8: Scaled conjugate gradient method architecture (After Kostopoulos and Grapsa, 2009)

In order to evaluate the authenticity in predicting the output (PPV and PF), the value of coefficient of determination (R^2) and also, root mean square error (RMSE) were critically perused

4.2 Validation and Verification

The validation of the developed equation by PCA and SSE has been done within the domain of statistical methods. This is also distinctly revealed by the nomenclating as internal validation. This internal validation has been done on the basis of real time field data driven statistical analysis.

After the validation of the equation, the AI tool (MLP technique) has been applied using the same parameters, which has been selected by PCA and SSE both. Since the ANN falls out of the purview of statistical methods and the relationship between input and output was found to be well established with the ANN method also. Therefore, outside the domain of statistical methods the ANN, doubly verifies the results and has been termed as verification. An overview of validation scheme is clearly illustrated in Figure 4.9.

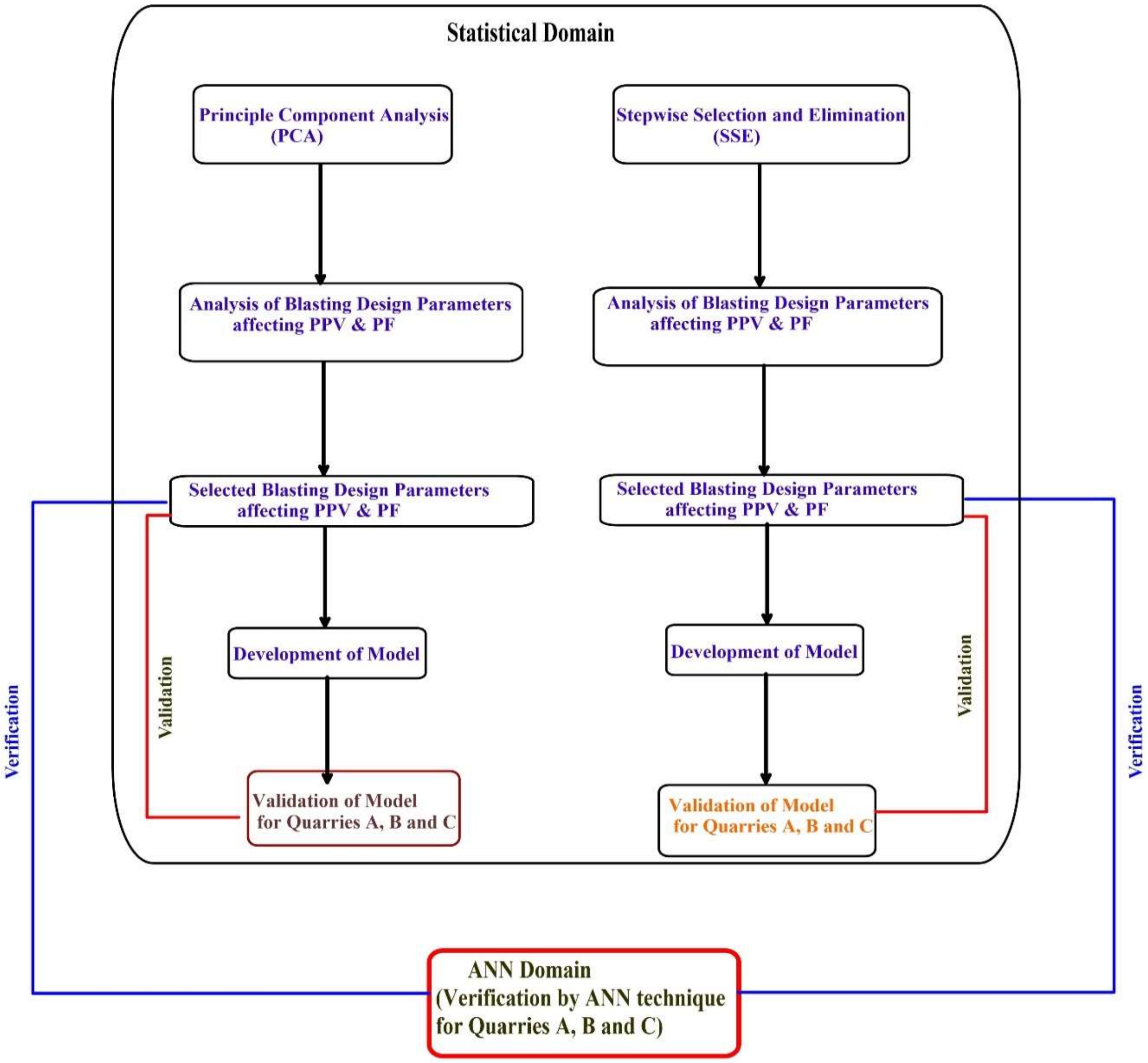


Figure 4.9: Flowchart of validation and verification

4.2.1 Validation with PCA

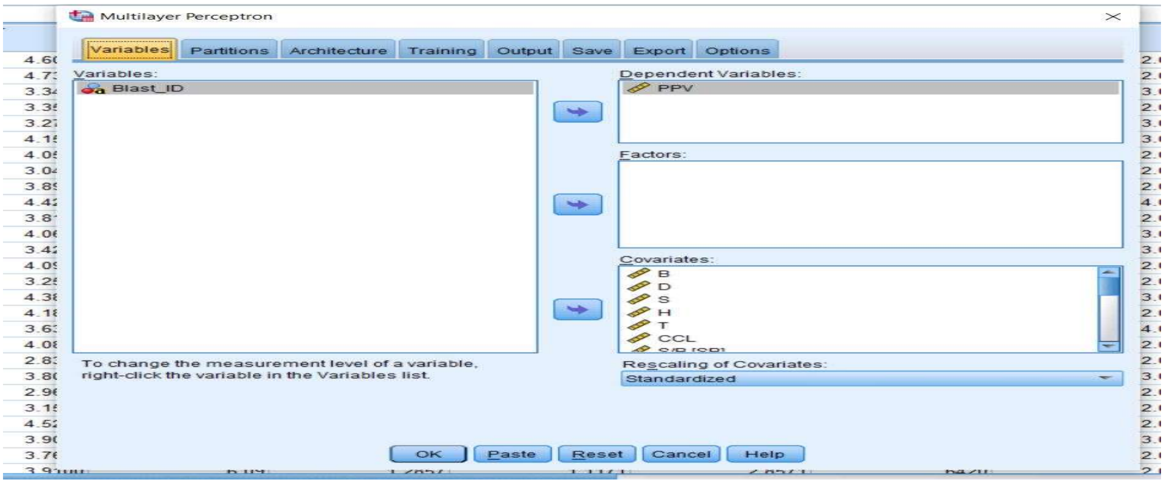
Equations developed in the form of statistical equations by PCA technique has been validated within the statistical domain on another blasting data sets for quarry A, quarry B and quarry C to ascertain the authenticity of the developed equation.

4.2.2 Validation with SSE

Equations developed in the form of statistical equations by SSE technique have been validated within the statistical domain on another blasting data sets for quarry A, quarry B and quarry C to ascertain the authenticity of the developed equation.

4.2.3 Verification by MLP Technique

The equations developed by PCA and SSE techniques have been verified by visiting outside the statistical domain by application of multi-layer perceptron ANN technique (AI method) on different blasting datasets from quarries A, B and C. The blasting design parameters, which were finally identified by PCA and SSE (statistical methods) were used as input variables and PPV and PF as output to carry out the MLP technique (Figure 4.10). Subsequently, the statistical equations have been verified by ANN technique.



Variables:
Blast_ID

Dependent Variables:
PPV

Factors:

Covariates:
B
D
S
H
T
CCL

To change the measurement level of a variable, right-click the variable in the Variables list.

Rescaling of Covariates:
Standardized

Figure 4.10: MLP technique after entering the variable.

CHAPTER 5

RESULTS AND DISCUSSION FOR PEAK PARTICLE VELOCITY (PPV)

5.1 Results obtained for all the quarries

The PCA and SSE followed by Multi-variate linear regression and ANN techniques have been employed to determine the blasting design and explosive parameters affecting ground vibrations. The equations developed by PCA and SSE have been used for validation (within the statistical domain) and the multi-layer perceptron (MLP) ANN technique has been used for verification outside the statistical domain. Further, the predicted values of PPV by PCA and SSE have been compared with the PPV values predicted by standard USBM square root equation. The results followed by discussion is presented in this chapter for all the three quarries.

In this research work, 19 blasting design parameters has been used. Some parameters are dependent on the other parameters like S/B, T/B, H/B depends on Burden (B). The PCA and SSE techniques has been carried out on these 19 parameters to select those, which are independent and not correlated among each other. For this, the term called variance inflation factor (VIF), which indicates the multi collinearity among parameters has been used to select the independent parameters. The VIF< 10, shows there is no any multicollinearity and VIF>10 shows the multicollinearity. So, the parameters which have VIF value less than 10 has been selected to develop the equation for the prediction of PPV and PF and other parameters has been rejected. By this way only independent parameters has selected at the final stage.

During the field studies, it was observed that the engineered Burden, Spacing and other blast geometry dimensions could not be implemented in real time (field blasting) because of: