Hindawi Publishing Corporation
Journal of Mining
Volume 2014, Article ID 618719, 9 pages
http://dx.doi.org/10.1155/2014/618719

Research Article

Rock Load Estimation in Development Galleries and Junctions for Underground Coal Mines: A CMRI-ISM Rock Mass Rating Approach

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Received 27 August 2013; Accepted 19 December 2013; Published 9 March 2014

Academic Editor: Manoj Khandelwal

Rock mass rating (RMR) plays important role in design and selection of support system (Ghosh, 2000). For stability assessment of rock mass it is very important to know the amount of rock load mobilized around the development gallery which is estimated using RMR (Singh et al., 2003, Barton et al., 1974, Bieniawski, 1984, and Ghosh et al., 1992). In Indian coal mines, Central Mining Research Institute-Indian School of Mines rock mass rating (herein after referred to as CMRI-ISM RMR) is mostly used for formulating design guidelines for supports. In this paper an attempt has been made to correlate CMRI-ISM RMR values and rock load of galleries and junctions for different gallery widths, ranging from 3.6 m to 4.8 m, at different densities of roof rocks. The proposed empirical expression can help in quick design of support system for underground coal mines working in the same regime.

1. Introduction

Roof and side falls in underground coal mines constitute the major reason for underground accidents and fatalities even today. Statistical analysis reveals that the share of roof and side falls contributes to 28.5% of the fatalities [1, 2]. After the development of CMRI-ISM RMR, an empirical approach for rock load estimation and support design in Indian underground mine roadways, the support related accidents have started declining though they still haunt the mining engineers every now and then. The RMR reflects the quality of roof in numeric terms and quantitative terms. It is based on five parameters and obtained after summation of all those five values. The obtained RMR is adjusted for different working conditions and then used to estimate the rock load mobilized around the galleries and junctions for design of support system for underground coal mines.

2. Study Area of Research Work

The case studies incorporated in this paper are taken from different mines of Bharat Coking Coal Limited and Tata Steel Limited situated in Jharia coalfield (Figure 1) [3]. Jharia coalfield, located in Dhanbad district of Jharkhand state, is one of the largest coalfields in India that has been actively associated with coal mining activities for more than a century. The study area lies in the heart of Damodar valley along the north of Damodar river. The coalfield is named after the chief mining centre, Jharia, situated in the eastern part of the coalfield. The coal basin extends for about 38 km in the east-west direction and a maximum of 18 km in the north-south direction covering an area of about 450 km^2.

2.1. CMRI-ISM RMR—An Overview. Rock mass rating (CMRI-ISM RMR) [4–9] determined by *CMRI-ISM Geomechanical Classification System* is the summation of the ratings of five individual parameters. The individual parameters and their maximum rating are provided in Table 1.

Layer thickness is very important, as delamination is a major causative factor for deterioration of roof condition [5]. For determining layer thickness, thickness of bedding plane is measured if roof is sandstone. In case of shale, thickness of bedding plane or thickness of lamination is measured. In case

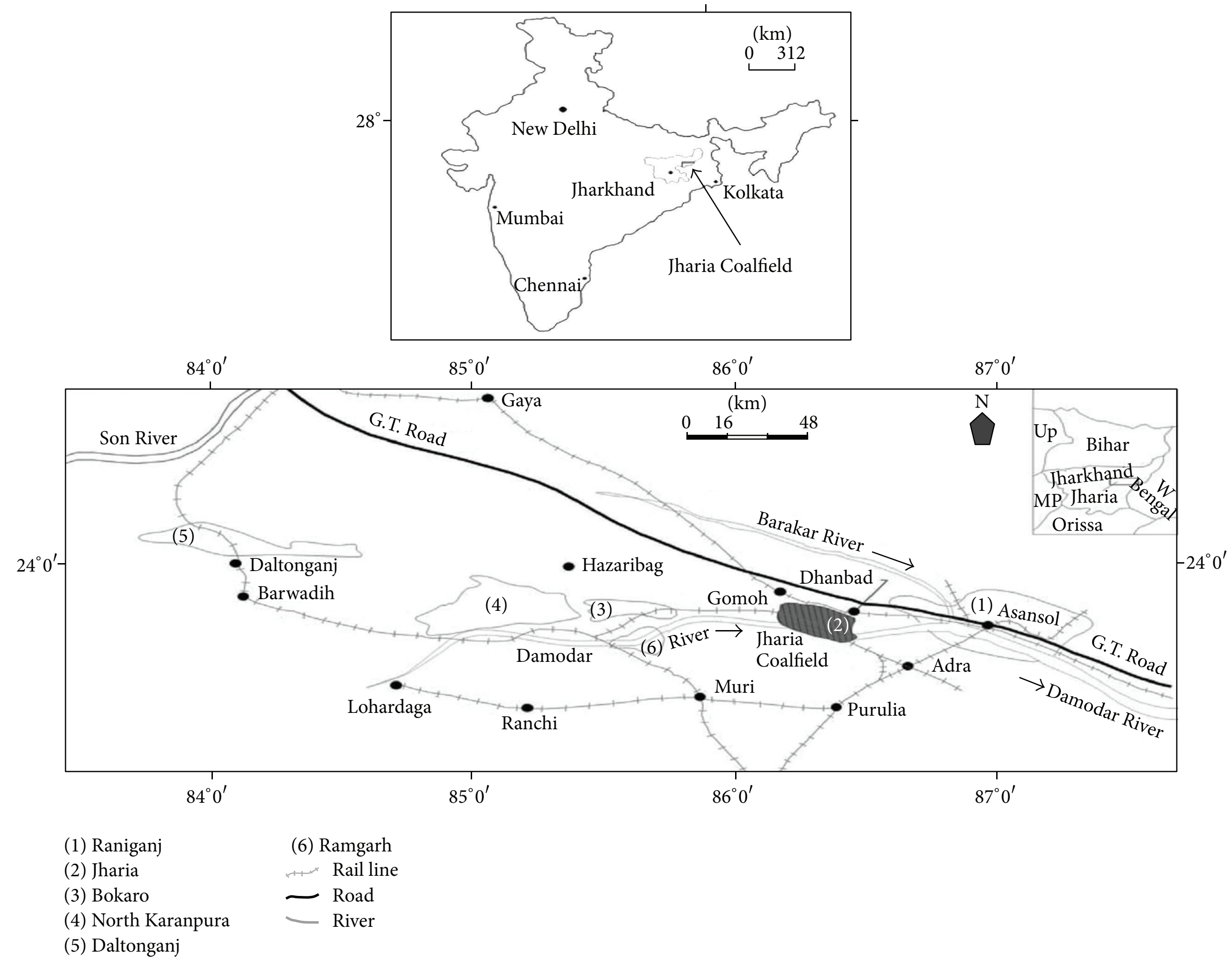

Figure 1: Location of Jharia coalfield in India.

Table 1: Parameters of CMRI-ISM rock mass rating.

Parameter	Maximum rating
Layer thickness (cm)	30
Structural features	25
Weatherability (1st cycle slake durability index)	20
Compressive strength (Kg/cm^2)	15
Groundwater condition (mL/min)	10

of coal roof, there are different small bands or layers of coal which are measured as layer thickness.

Structural features are geological structures which cause roof deterioration and constitute major faults, slips, joints, and other sedimentary features like sandstone channel, plant impression, and so forth. Water percolation is the major problem in Indian coal mines; thus, weatherability is important because many coal measure rocks become weak or disintegrate due to weathering, especially in presence of water. The measure for this parameter is the 1st cycle slake durability index (SDI) determined by slake durability apparatus [10]. Compressive strength of rock is determined in the laboratory as per Bureau of Indian Standards [11].

Groundwater seepage is measured by drilling a 1.5 to 1.8 m long hole in roof and thereafter collecting the water percolation through it. The rate of percolation is expressed in mL/min.

Adjustments for depth, lateral stress, induced stresses, method of excavation, and gallery span are made for accounting their positive, neutral, and negative contribution to RMR values as given in Table 2.

After due adjustment, adjusted RMR is used for estimation of rock load in galleries and junctions from the following equations:

$$\text{Rock load in roadways } \left(t/m^2\right) = B \cdot D \cdot \left(1.7 - 0.037\,\text{RMR} + 0.0002\,\text{RMR}^2\right), \quad (1)$$

$$\text{Rock load in junctions } \left(t/m^2\right) = 5 \cdot B^{0.3} \cdot D\left(1 - \frac{\text{RMR}}{100}\right)^2, \quad (2)$$

Table 2: Adjustment factors for RMR.

Parameter	Adjustment of RMR	Adjusted RMR
(1) Depth		
Less than 250 m	Nil	RMR × 1.0
250–400 m	10% reduction	RMR × 0.9
400–600 m	20% reduction	RMR × 0.8
More than 600 m	30% reduction	RMR × 0.7
(2) Lateral stresses		
Small	10% reduction	RMR × 0.9
Moderate	20% reduction	RMR × 0.8
High	30% reduction	RMR × 0.7
(3) Induced stresses		
No adjacent working in the seam	Nil	RMR × 1.0
Extraction areas within 20–40 m in the same seam	10% reduction	RMR × 0.9
Extraction areas within 10–20 m in the same seam	Up to 30% reduction	RMR × (0.7 to 0.8)
Working with 10–20 parting	10% reduction	RMR × 0.9
Working with 3–10 m parting	Up to 30% reduction	RMR × (0.7 to 0.8)
(4) Method of excavation		
Continuous miner	10% increase	RMR × 1.1
Undercut and blasting	Nil	RMR × 1.0
Blasting off the solid	10% reduction	RMR × 0.9
(5) Gallery span		
Less than 4.8 m	Nil	RMR × 1.0
4.8–6.0 m	10–20% reduction	RMR × (0.8 to 0.9)

where RMR = rock mass rating, B = roadway width (m), and D = dry density (t/m^3).

3. Rock Load Estimation for Galleries and Junctions: Some Field Studies

Field studies were conducted in different mines and RMR was determined. For determination of RMR three parameters, namely, layer thickness, structural features, and groundwater, were collected during geotechnical studies of roof rocks in the mine site. Compressive strength and 1st cycle slake durability index were determined in the laboratory. The details of investigations carried out are provided in Table 3. The cases are classified based on gallery width, that is, 3.6 m, 4.2 m, and 4.8 m, respectively.

4. Analysis of Investigations

4.1. Mine Development Galleries. The correlation analysis done between CMRI-ISM RMR and estimated rock load of galleries (with the suggested rock load equation (1)) was statistically analyzed using least square regression method. (Table 3). Equations have been developed for 3.6 m, 4.2 m

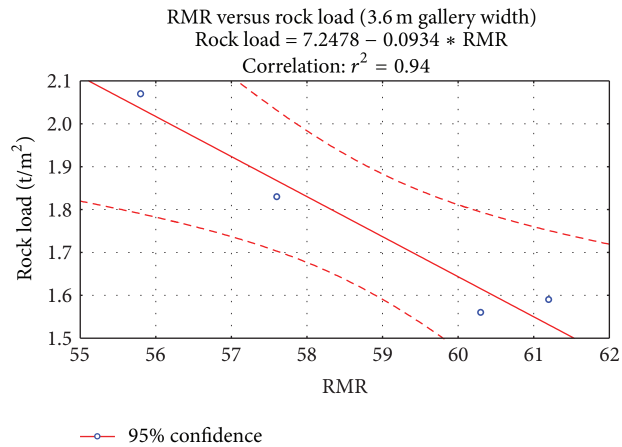

Figure 2: Correlation between RMR and rock load for 3.6 m gallery width.

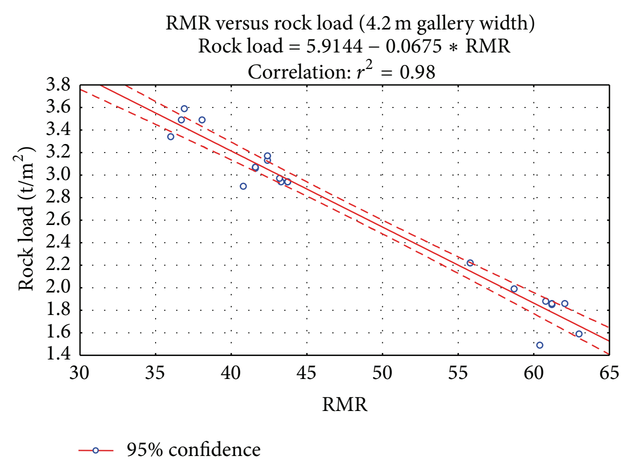

Figure 3: Correlation between RMR and rock load for 4.2 m gallery width.

and 4.8 m gallery width using different range of densities. The equation of best fit line and coefficient of determination (R^2) were determined for each regression (Figures 2–4). Minimum R^2 value obtained in this analysis is 0.86 for 4.8 m gallery width. The results of regression equation and the coefficient of determination are presented in Table 5. A linear relationship was observed in all three cases.

Correlation between RMR and Rock Load for 3.6 m Gallery Width. See Figure 2.

Correlation between RMR and Rock Load for 4.2 m Gallery Width. See Figure 3.

Correlation between RMR and Rock Load for 4.8 m Gallery Width. See Figure 4.

4.2. Junctions. The correlation analysis done between CMRI-ISM RMR and estimated (estimated using (2)) rock load of junctions was statistically analyzed using least square regression method (Table 3). The equations have been developed for

Table 3: RMR and rock load estimation for galleries and junctions for different mines.

S. number	Name of the mine	Density (t/m^3)	RMR	Rock load in gallery (t/m^2)	Rock load in junction (t/m^2)
For 3.6 m gallery width where roof rock density varied from 2.2 t/m^3 to 2.4 t/m^3 % variation of RMR and density from minimum value is up to 9.6% and 9.5%, respectively					
1	Huriladih	2.19	57.6	1.83	2.89
2	Block IV	2.21	60.3	1.56	2.55
3	Sudamdih	2.4	61.2	1.59	2.65
4	Huriladih	2.23	55.8	2.07	3.19
For 4.2 m gallery width where roof rock density varied from 1.27 t/m^3 to 2.55 t/m^3 % variation of RMR and density from minimum value is up to 75% and 87.5%, respectively					
1	Bagdighi	2.55	62.05	1.86	2.82
2	Jogidih	2.38	61.2	1.85	2.76
3	Khas Kusunda	2.18	58.7	1.99	2.86
4	Khas Kusunda	2.32	63	1.59	2.44
5	Damoda	2.4	61.2	1.86	2.77
6	Sendra Bansjora	2.05	55.8	2.22	3.07
7	Dobari	1.82	60.4	1.49	2.19
8	Tetulmari	2.37	60.8	1.88	2.8
9	Sendra Bansjora (Bot)	1.43	38.07	3.49	4.22
10	Gopalichack	1.48	43.3	2.94	3.66
11	Kusunda	1.36	36.7	3.49	4.19
12	Bagdighi	1.36	40.8	2.9	3.66
13	East Bhuggatdih	1.52	42.4	3.13	3.88
14	Damoda (BJ Pit)	1.27	36	3.34	4
15	Amlabad	1.44	41.6	3.06	3.78
16	Alkusha	1.49	43.2	2.97	3.69
17	Nichitpur	1.54	42.4	3.17	3.93
18	Industry	1.41	36.9	3.59	4.32
19	Ramkanali	1.44	41.6	3.07	3.78
20	Mudidih (Pit number 3)	1.51	43.74	2.94	3.67
For 4.8 m gallery width where roof rock density varied from 1.35 t/m^3 to 2.4 t/m^3 % variation of RMR and density from minimum value is up to 51.4% and 76.4%, respectively					
1	Godhur	1.48	45	3.2	3.5
2	South Balihari	1.39	42.4	3.27	3.6
3	Huriladih	1.35	41.6	3.28	3.6
4	Godhur incline	1.47	43.2	3.35	3.8
5	Mahamaya mine, SECL	1.9	61.2	1.58	2.2
6	Churcha mine, SECL	2.4	56.7	2.82	3.6
7	Shivani mine, SECL	2.15	57.6	2.4	3.0
8	Baherabad mine, SECL	2.26	63	1.76	2.4

junctions formed with 3.6 m, 4.2 m, and 4.8 m wide galleries using different range of densities. The equation of best fit line and coefficient of determination (R^2) were determined for each regression (Figures 5–7). Minimum R^2 value obtained here is 0.72 for junctions formed with 4.8 m gallery width. The results of regression equation and the coefficient of determination are presented in Table 5. A linear relationship has been observed in all three cases.

Correlation between RMR and Rock Load for Junctions Formed with 3.6 m Wide Gallery. See Figure 5.

Correlation between RMR and Rock Load for Junctions Formed with 4.2 m Wide Gallery. See Figure 6.

Correlation between RMR and Rock Load for Junctions Formed with 4.8 m Wide Gallery. See Figure 7.

Table 4: Estimated rock load for 3.6 m, 4.2 m and 4.8 m wide galleries and junctions.

Estimated rock load (CMRI-ISM RMR)		Estimated rock load (best fit equation)		
Gallery (t/m^2)	Junction (t/m^2)	Gallery (t/m^2)	Junction (t/m^2)	
1.8	2.8	2.1	2.9	For 3.6 m wide galleries
1.5	2.5	1.8	2.7	
1.5	2.6	1.7	2.6	
2.0	3.1	2.2	3.1	
1.8	2.8	1.7	2.6	For 4.2 m wide galleries
1.8	2.7	1.8	2.6	
1.9	2.8	1.9	2.8	
1.5	2.4	1.6	2.5	
1.8	2.7	1.8	2.6	
2.2	3.0	2.1	2.9	
1.4	2.1	1.8	2.7	
1.8	2.8	1.8	2.6	
3.4	4.2	3.3	4.0	
2.9	3.6	3.0	3.7	
3.4	4.1	3.4	4.1	
2.9	3.6	3.1	3.8	
3.1	3.8	3.0	3.8	
3.3	4.0	3.5	4.1	
3.0	3.7	3.1	3.8	
2.9	3.6	3.0	3.7	
3.1	3.9	3.0	3.8	
3.5	4.3	3.4	4.1	
3.0	3.7	3.1	3.8	
2.9	3.6	2.9	3.7	
3.2	3.5	3.1	3.6	For 4.8 m wide galleries
3.2	3.6	3.3	3.7	
3.2	3.6	3.4	3.8	
3.3	3.8	3.3	3.7	
1.5	2.2	1.9	2.7	
2.8	3.6	2.3	2.9	
2.4	3.0	2.2	2.9	
1.7	2.4	1.8	2.6	

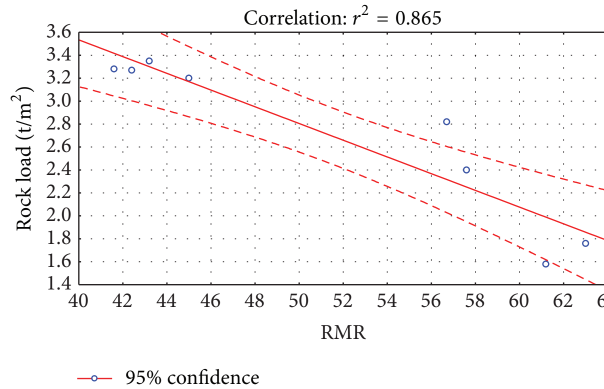

Figure 4: Correlation between RMR and rock load of 4.8 m gallery width.

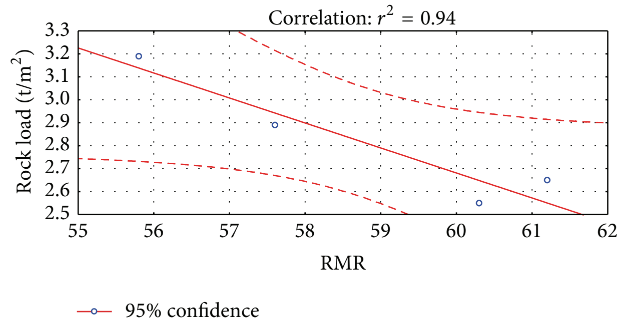

Figure 5: Correlation between RMR and rock load of junctions (3.6 m wide galleries).

5. Correlation of Estimated Rock Load for Galleries and Junctions

The estimated rock load which is obtained from CMRI-ISM RMR is correlated with the estimated rock load determined for both galleries and junctions which is arrived at by best fit equations in the analysis for 3.6 m, 4.2 m, and for 4.8 m galleries as well as for junctions formed with 3.6 m, 4.2 m, and 4.8 m galleries (Table 4). The estimated rock load from developed best fit equations is presented Table 5. Here also very good correlation is obtained in all the cases which are shown in the figures (Figures 8–13). The error in the estimated value is represented by the distance of each data point from the 1 : 1 slope line. A point lying on the 1 : 1 slope line shows an accurate estimation, whereas points away from the line show the error as shown in Figures 2–12. Equations for statistical analysis are selected, so that the coefficient of determination (R^2) value should be more than 0.72 in all six cases which is acceptable for establishment of correlation equations.

Correlation between Estimated Rock Load for 3.6 m Wide Gallery and Junctions. See Figures 8 and 9.

Correlation between Estimated Rock Load for 4.2 m Wide Gallery and Junctions. See Figures 10 and 11.

Correlation between Estimated Rock Load for 4.8 m Wide Gallery and Junctions. See Figures 12 and 13.

6. Student's t-Test

The significance of R-values can be determined by the t-test assuming that both variables are normally distributed and the observations are chosen randomly. The test finds the t-value and check the significance of the input values of the equations. If the P value (level of significance %) is less than 0.05, then it is said that the data which is used is statistically significant,

Table 5: Regression equations between CMRI-ISM RMR and rock load of galleries and Junctions.

Case number	Parameters	Regression equations	R^2 value
1	RMR versus rock load (for 3.6 m wide galleries)	R/L(galleries) = 7.2 − 0.09 ∗ RMR	0.94
2	RMR versus rock load (for 4.2 m wide galleries)	R/L(galleries) = 5.9 − 0.06 ∗ RMR	0.98
3	RMR versus rock load (for 4.8 m wide galleries)	R/L(galleries) = 6.4 − 0.07 ∗ RMR	0.86
4	RMR versus rock load (for 3.6 m wide junctions)	R/L(junctions) = 9.2 − 0.10 ∗ RMR	0.94
5	RMR versus rock load (for 4.2 m wide junctions)	R/L(junctions) = 6.3 − 0.06 ∗ RMR	0.96
6	RMR versus rock load (for 4.8 m wide junctions)	R/L(junctions) = 6.1 − 0.05 ∗ RMR	0.72

Table 6: t-test for independent samples (variables treated as independent samples).

S. number	Group 1 versus group 2	Mean group 1	Mean group 2	t-value	df	P (level of significance)	Remarks
1.	RMR versus calculated rock load (gallery width 3.6 m)	67.5	21.8	2.0	8	0.05	Number of data are less
2.	RMR versus calculated rock load (junctions)	67.5	22.6	2.0	8	0.05	
3.	RMR versus calculated rock load (gallery width 4.2 m)	51.0	7.3	7.5	40	0.000000	Number of data are good
4.	RMR versus calculated rock load (junctions)	51.0	8.1	7.4	40	0.000000	
5	RMR versus calculated rock load (gallery width 4.8 m)	51.3	2.7	15.0	14	0.000000	Number of data are moderate
6	RMR versus calculated rock load (junctions)	51.3	3.2	14.8	14	0.000000	

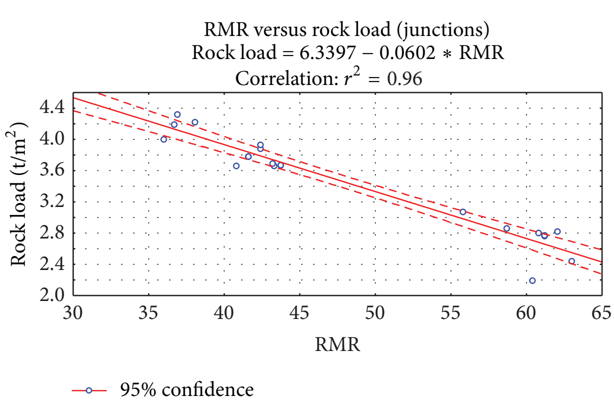

Figure 6: Correlation between RMR and rock load of junctions (4.2 m wide galleries).

t-test used for comparing the means of two variables even if they have different number of replicates. In general term t-test compares the actual difference between two means in relation to the variation in data. The formula for the t-test is the ratio in which the numerator is just the difference between two means or average and denominator is a measure of variability or dispersion. Consider

$$t = \frac{\left(\ddot{X}_T - \ddot{X}_C \right)}{\sqrt{\mathrm{Var}_T / n_T + \mathrm{Var}_C / n_C}}. \quad (3)$$

From Table 6 it is seen that in all of the three cases the value of P (level of significance) is <0.05 which is the value to check the significance of the input data, whether they are statistically significant or not. Thus it may be concluded that a high degree of correlation has been seen between CMRI-ISM RMR and best fit equations estimated rock load values for galleries and junctions. Thus the obtained equations are acceptable for future application in similar geo-mining regime.

7. Predictability of the Derived Equations

An analysis is carried out to study the influence of varying RMR on rock load estimated from best fit equations to assess the behavior of the developed equations for the both galleries

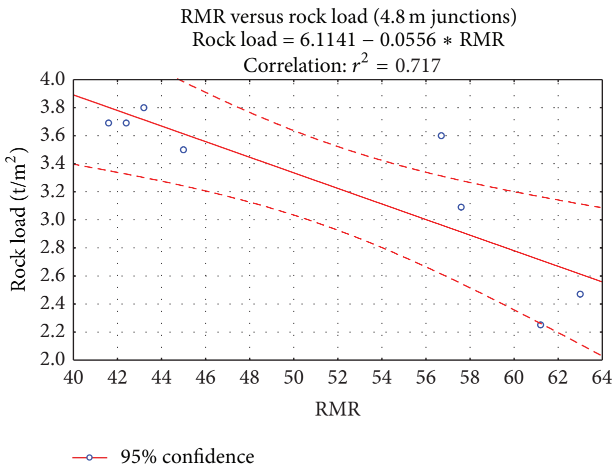

Figure 7: Correlation between RMR and rock loads of Junctions (4.8 m wide galleries).

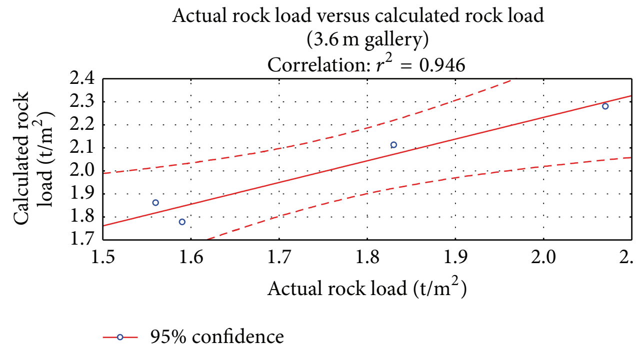

Figure 8: Correlation between estimated rock loads for 3.6 m galleries.

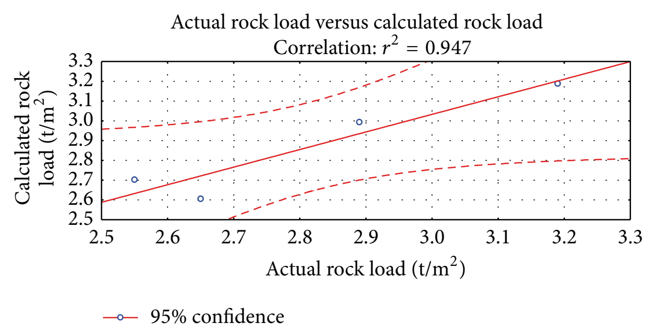

Figure 9: Correlation between estimated rock loads for junctions.

and junctions with the varying width from 3.6 m to 4.8 m (Figures 14 and 15). It may be seen that in some case for the less gallery width the rock load obtained is on higher side for both galleries and junctions when the gallery and junction width were less (3.6 m). This transition line was at RMR value of 50 for galleries and 60 for junctions. A normal trend of reduced rock load was seen with reduced galleries width at higher values of RMR.

8. Conclusion

(1) This study indicates that the rock load of galleries and junctions of various coal measures rocks of India can be estimated by using simple empirical relationships after substituting only the value of RMR. All the six cases showed linear relationship with each other.

(2) The empirical expressions for rock load estimation in coal measure roof rocks for 3.6 m, 4.2 m and 4.8 m, gallery width are as follows:

$$\begin{aligned}
&\text{Rock Load (galleries of 3.6 m)} = 7.2 - 0.09 * \text{RMR}, \quad R^2 = 0.94,\\
&\text{Rock Load (galleries of 4.2 m)} = 5.9 - 0.06 * \text{RMR}, \quad R^2 = 0.98,\\
&\text{Rock Load (galleries of 4.8 m)} = 6.4 - 0.07 * \text{RMR}, \quad R^2 = 0.86,\\
&\text{Rock Load (junctions of 3.6 m)} = 9.2 - 0.10 * \text{RMR}, \quad R^2 = 0.95,\\
&\text{Rock Load (junctions of 4.2 m)} = 6.3 - 0.06 * \text{RMR}, \quad R^2 = 0.96,\\
&\text{Rock Load (junction of 4.8 m)} = 6.1 - 0.05 * \text{RMR}, \quad R^2 = 0.72.
\end{aligned} \tag{4}$$

(3) Strong coefficient of determination was found in all the six cases shown.

(4) Developed equations are applicable for 3.6 m, 4.2 m, and 4.8 m gallery width with density in the range of 2.2 t/m^3–2.4 t/m^{3}for 3.6 m gallery width, 1.27 t/m^3–2.55 t/m^3 for 4.2 gallery width, and 1.35 t/m^3–2.4 t/m^3 for 4.8 m gallery width.

(5) Equations are practical, simple, and reasonably accurate to apply.

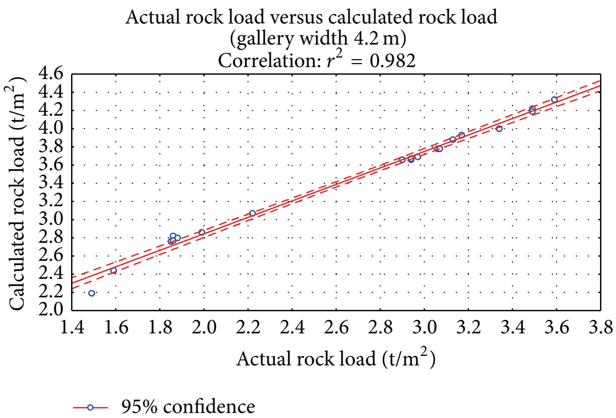

FIGURE 10: Correlation between estimated rock loads for 4.2 m galleries.

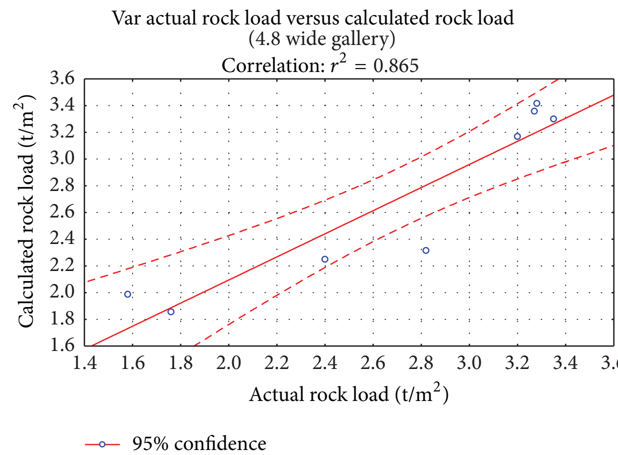

FIGURE 12: Correlation between estimated rock loads for 4.8 m wide galleries.

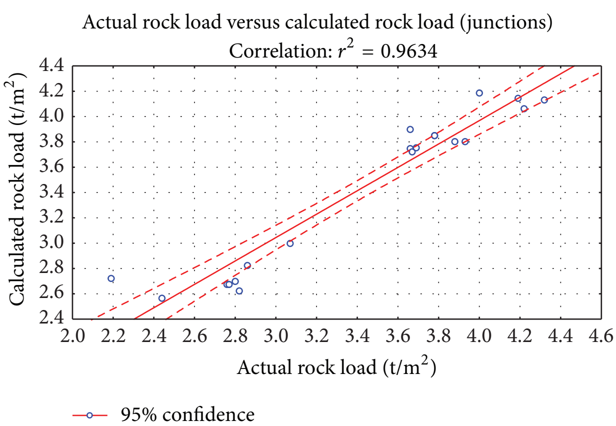

FIGURE 11: Correlation between estimated rock loads for junctions.

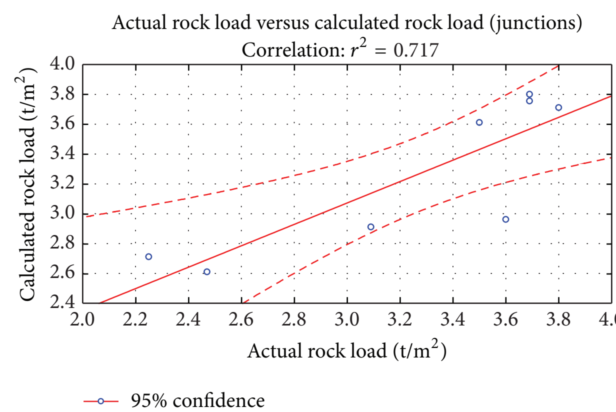

FIGURE 13: Correlation between estimated rock loads for 4.8 m wide galleries and junctions.

(6) This study, coupled with judicious judgment, can be helpful for arriving at the initial estimates of rock loads in development galleries and junctions of underground coal mines and thus can help in support design with greater safety and stability for Indian geomining conditions.

(7) The variation in rock load behavior in different gallery widths can be attributed to variation in roof rocks density and RMR range. Lack of enough data sets also lead to this variation thus pointing to the need for including more data for realistic predictions. A relook into the parameters considered for rock load estimation is also necessary to make more wholesome predictions.

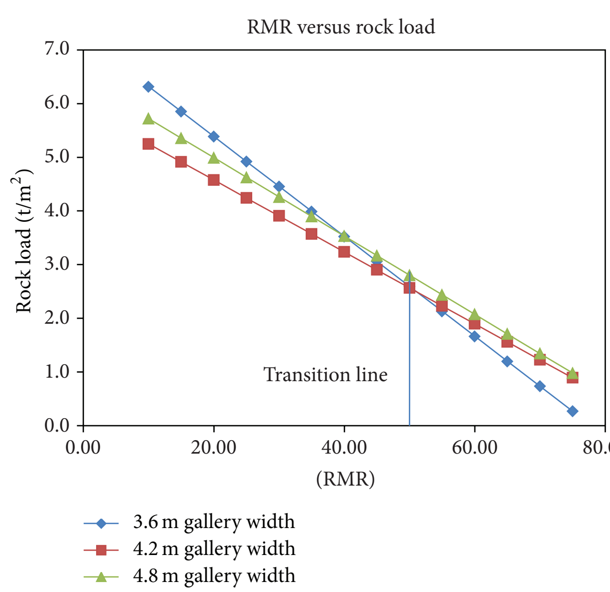

FIGURE 14: Plot between assumed RMR and rock load for 3.6, 4.2, and 4.8 m galleries.

Abbreviations

CMRI-ISM: Central Mining Research Institute-Indian School of Mines
RMR: Rock mass rating
R/L: Rock load
BCCL: Bharat Coking Coal Limited.

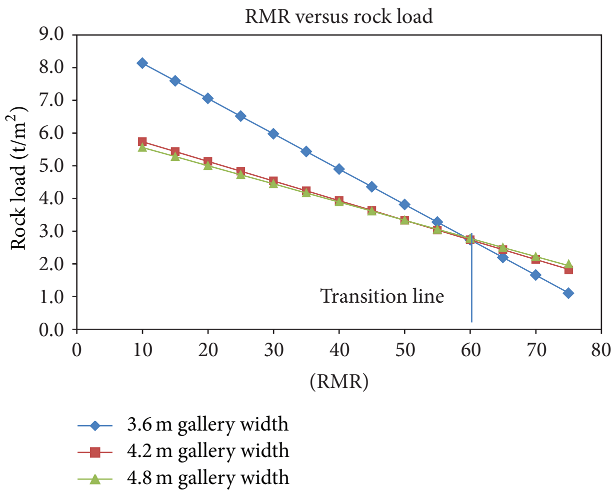

FIGURE 15: Plot between assumed RMR and rock load for 3.6, 4.2, and 4.8 m junctions.

Conflict of Interests

The authors declare that they do not have conflict of interests regarding of the publication of this paper.

Acknowledgments

The authors would like to thank the Director of CIMFR, Dhanbad, and Director of ISM, Dhanbad and also the Mine Management for their kind support during the research work. The authors are also thankful to Mr S K Singh Senior Principal Scientist and Head, Geo-mechanical Lab. CIMFR, Dhanbad for his sincere help during testing of rock samples. The work forms a part of the Ph.D. work of the first author being carried out at ISM, Dhanbad, Jharkhand, India.

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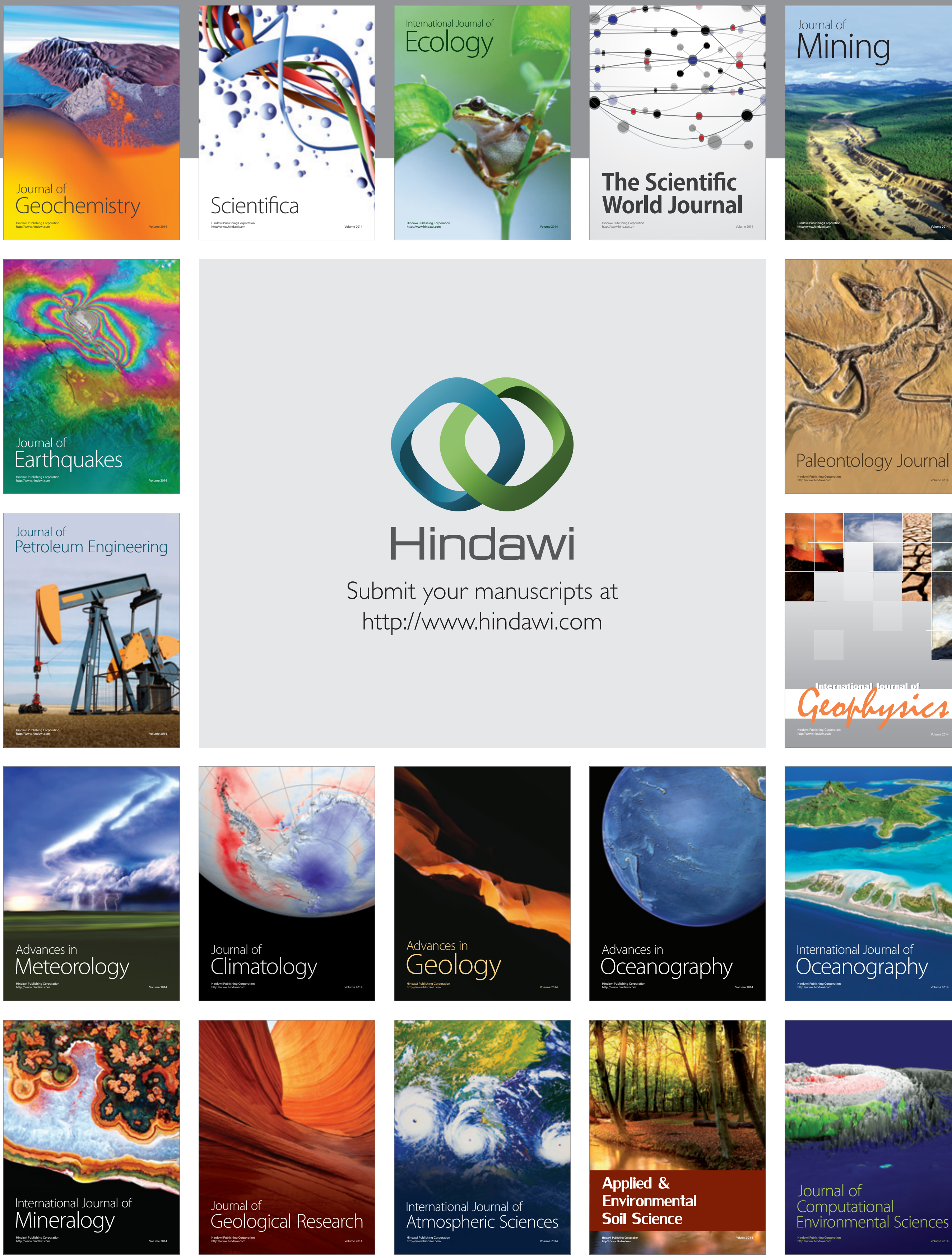
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