STABILITY ANALYSIS OF COAL GALLERY USING A NEW GEO-MECHANICAL CLASSIFICATION - COAL ROOF INDEX

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By

Sonu

DEPARTMENT OF MINING ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI - 221005
(INDIA)

Roll No: 18151506

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Chapter 6
Conclusions and Future Work

6.1 General

The evaluation of the roof's rock-mass characterization is crucial for determining the necessary roof support. The *CRI*, a rock-mass classification system for coal roof rocks, was developed through the statistical analysis of forty-four Indian coal field cases. Greater depth tends to increase the extent of the plastic zone due to higher overburden pressure, while a wider gallery typically results in a larger plastic zone because of increased stress redistribution. Proper engineering design must account for these factors to maintain stability and safety in underground mining operations. Consequently, the combined effect of the depth and width of the gallery is represented by the *RLF* in the current classification system. Additionally, time-dependent strength degradation is an important aspect of studying rock failure behavior. Therefore, numerical analysis has been conducted considering various stable and failed cases of Indian coalfields. The findings of this research are summarized in the subsequent section.

6.2 Conclusions

The conclusions extracted from this research are summarised as follows:

1. The suggested classification scheme is based on multiplying the ratings of the five influencing factors—*Gw*, *LTH*, weatherability, *SF*, and *UCS* of roof strata. The proposed *CRI* formulation is as follows:

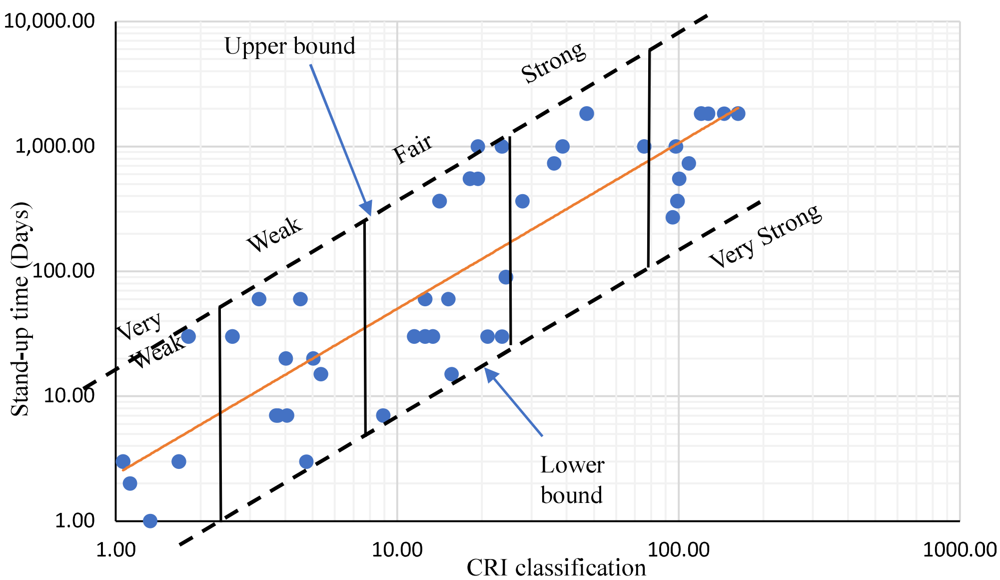
   $$CRI = \left(\frac{R_{CRI\_1}}{R_{CRI\_2}}\right) X \left(\frac{R_{CRI\_3}}{R_{CRI\_4}}\right) X\ R_{CRI\_5}$$

   But the depth, width, and height of the gallery are directly affected to the unsupported span, excavation cycle, and support design. Therefore, the author has introduced the '*RLF*' for the combined effect of the dimensions of the gallery and stress conditions. The adjusted *CRI* has been determined by the division of *CRI* to the rating of six parameters (*RLF*) as follows:

$$\text{Adjusted } CRI = \frac{\text{CRI}}{\text{R}_{\text{CRI\_6}}}$$

$$\text{Adjusted } CRI = (\frac{\text{R}_{\text{CRI\_1}}}{\text{R}_{\text{CRI\_2}}}) \text{ X } (\frac{\text{R}_{\text{CRI\_3}}}{\text{R}_{\text{CRI\_4}}}) \text{ X } \frac{\text{R}_{\text{CRI\_5}}}{\text{R}_{\text{CRI\_6}}})$$

2. The adj. CRI ranges from 0.001 to 1000. Seven classes have been identified based on the CRI: Extremely Weak (*CRI*: 0.001 – 0.1), Very Weak (*CRI*: 0.1 – 2.5), Weak (*CRI*: 2.5 – 7.5), Fair (*CRI*: 7.5 - 25), Strong (*CRI*: 25 - 4), Very Strong (*CRI*: 75 - 400), and extremely strong (*CRI*: exceeding 400). Most of the coal roof rocks fall into five classes, as shown in the Fig. below.



3. While *LTH*, SDI, and *UCS* of roof strata show a positive influence on the *CRI*, as well as *SF*, *Gw*, and *RLF* show a negative influence on *CRI*. When weatherability is less than 95%, *Gw* must be taken into account.

4. The suggested *CRI* value and the *ST* had a respectable correlation, according to a statistical analysis of the large range of roof rock quality. According to this study, there is a linear logarithmic relationship between the unsupported roof's *ST* and *CRI*, which is as follows:

$$Log\ (ST) = 1.5746\ Log\ (CRI)$$

The suggested *CRI* classification has a strong correlation with observed standup time for all 44 cases. The coefficients of determination (R^2) are 0.78.

5. Additionally, an exponential correlation has been found between the suggested *CRI* and the *CMRI-RMR*. The following is the established exponential relationship:

$$CRI = 0.0788e^{0.1049\ RMR}$$

6. This study conducted a three-dimensional numerical analysis of the distribution of plastic strain around a gallery of thirty-five Indian coal mine cases. The goal of the study was to develop an understanding of the plastic strain distribution around the gallery and to identify critical zones.

7. The model has established a relationship between the *CRI* and the Hooke-Brown strength parameters. The equations relating the *CRI* to the peak strength parameters '*m*, *s*, and *a*' are as follows:

$$m = 1.5651 \text{ x CRI}^{0.1013}$$

$$s = 0.005 \text{ x CRI}^{0.7225}$$

$$a = 0.7096 \text{ x CRI}^{-0.041}$$

8. The predictive *ST* relation has also been developed. The developed equation is based on the time of fall for the roof as obtained from different mines data and the plastic

strain calculated by the numerical simulation based on different parameters and conditions of field cases. The following equation has been obtained between the time of fall and the plastic strain:

$$ST = 0.1137*PS^{-1.088}$$

9. The author has suggested the limit of critical plastic strain based on *ST* such as- for immediate roof failure cases ($\varepsilon_p > 5 \times 10^{-3}$), critical plastic strain for short-term stable cases ($1 \times 10^{-3} < \varepsilon_p < 5 \times 10^{-3}$), and critical plastic strain for stable cases ($\varepsilon_p < 1 \times 10^{-3}$) strains in the immediate roof before and after installation of roof bolt supports. It will help geotechnical engineers to assess and optimize the cost of support installation as per the needs of working conditions.

10. The empirical formulation for estimation of rock load at the gallery has been proposed using a numerical simulation approach based on the yielding zone of the roof (or zone of plastic strain). The following equation has been proposed between the *CRI* Classification and the rock load:

$$RLH = 1.248 \times w \times CRI^{-0.421}$$

$$RL_{Gallery} = 1.248 \times w \times D \times CRI^{-0.421} \qquad (R^2 = 0.85)$$

11. The current support design system takes the safety factor of 1.5 into account when designing for short-term stability and the safety factor of 2 into account when designing for long-term stability. However, the proposed simulation scheme for roof support design is based on plastic strain. As expressed in the above equation, a reasonably good correlation has been observed between rock load and *CRI* classification. Thus, the numerical analyst may suggest the appropriate roof support system based on its life span.

12. In this study, 34 Indian coal mine cases (immediate failure cases, short-term stable cases, and long-term stable cases) have been numerically simulated using the *FLAC 3D* tool, considering the time-dependent elastic-perfectly plastic-strain softening (*TDEPPSS*) constitutive model. The study aimed to develop a time-dependent constitutive model for an underground coal roof. The model has established a time-dependent strength reduction formulation with time and the *CRI*. The equations are as follows:

$$\beta = 0.8986\ X\ e^{-0.014\ X\ t}$$

$$m_{rmt} = (0.25+0.75\ x\ \beta)\ x\ m_{rm}$$

$$s_{rmt} = \beta\ x\ s_{rm}$$

13. The predicted life of the gallery, based on the deduced material properties, was compared with the actual *ST* of the gallery. In the comparison of the predicted *ST* with the actual *ST* of all cases, except for five instances, the predicted *ST* is generally close to the actual *ST*.

14. It was observed that the mine roof deteriorates with time, and roof deformation increases with the life of the gallery. The *TDEPPSS* constitutive model helps design an underground coal gallery and optimizes the cut-out distance in continuous mine operation.

6.3 Future scope of work

1. The present study considers a few cases for the validation of *CRI* classification. More field cases could be included to validate the proposed *CRI* classification of roof rock. A software application can be developed to calculate the *CRI* value and estimate of *ST*.

2. The present study did not conduct any laboratory tests to deduce the strength properties of Indian coal. Instead, logical analysis was considered to deduce the time-dependent *H-B* strength properties; however, future work should aim to include laboratory experiments to validate and refine these deduced properties for improved reliability.

3. As the Rock load formulation for coal gallery is proposed based on numerical simulation techniques and is validated through five field cases, there is a need for validation of this with field-measured rock load by instrumentation data.

4. Field measurements of roof deformation in a coal gallery during the development phase can be used for further validation of the proposed roof deformation formulation through an explicit simulation approach.