ISSN: 2633-4828 Vol. 5 No.4, December, 2023

International Journal of Applied Engineering & Technology

# EVALUATION OF PILLAR DESIGN SAFETY IN UNDERGROUND COAL MINES: A COMPARATIVE ANALYSIS OF CMRI, BIENIAWSKI, AND OBERT-DUVALL APPROACHES

**Thadaka Nikhil[1], Dr. Rajni Kant[2] and Shailendra Bommanwar[3]**
[1]Research Scholar, Department of Mining Engineering, BIT, Ballarpur (MS),India
[2]Principal, Ballarpur Institute of Technology Ballarpur Dist-Chandrapur(MS)-442701
[3]Assistant Professor, Department of Mining Engineering, BIT, Ballarpur (MS)

## ABSTRACT

*Effective pillar design is crucial for the safety and efficiency of underground coal mining operations. This study evaluates the predictive accuracy of three established pillar design methodologies—CMRI, Bieniawski, and Obert-Duvall—under the specific conditions prevalent in Indian coal mines. The analysis involved a comparative assessment of safety factors predicted by each method at various depths and pillar dimensions. Data from several coal mines across India were used to calculate theoretical safety factors, which were then refined through regression analysis to develop predictive models. The study found that the CMRI method generally provides the highest safety factor predictions, often exceeding the minimum safety standards, while the Bieniawski method tends to underestimate safety factors, potentially compromising pillar stability. The Obert-Duvall method offers a balanced prediction, aligning closely with the practical requirements of mine safety. The findings highlight the necessity for mine operators to adapt pillar design practices based on specific geological and operational conditions to ensure safety and optimize resource extraction. Recommendations include further research incorporating a broader dataset and the development of hybrid models that merge the strengths of existing methodologies. The study contributes to the field of mining engineering by enhancing the understanding of how different pillar design formulas can be applied and adjusted for optimal safety and efficiency in underground coal mines.*

*Keywords: Pillar design, Underground mining, Safety factor, CMRI, Bieniawski, Obert-Duvall, Mining depth, Coal mining, Geotechnical stability*

## INTRODUCTION

The structural integrity and safety of underground mining operations are critically dependent on the design of mine pillars. These pillars not only support the overburden but also dictate the overall safety and productivity of the mining operations. The conventional approach to designing these structures often involves balancing between resource extraction and ensuring adequate safety margins, influenced by a variety of geotechnical factors.

This study provides a comprehensive evaluation of three prevalent methodologies in pillar design: the Central Mining Research Institute (CMRI) method, the Bieniawski method, and the Obert-Duvall method. Each method offers different perspectives on safety factors, which are essential for ensuring the stability of mine structures under various operational conditions. The effectiveness of these methods is assessed by examining their response to changes in mining depth, pillar dimensions, and other geotechnical parameters in the context of Indian underground coal mines.

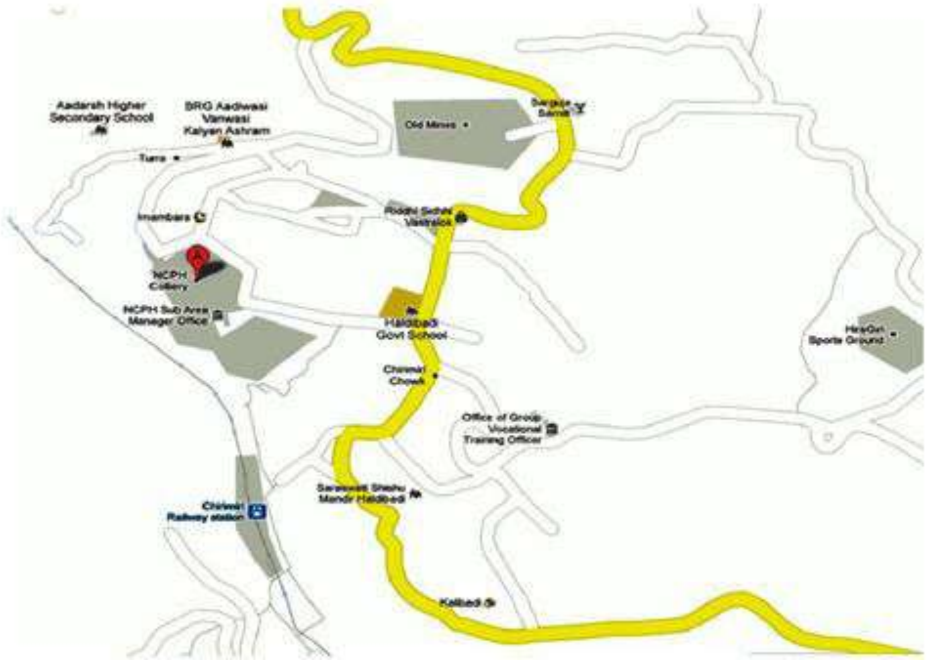


**Figure-1:** Location of Field Investigation mine site

A significant aspect of this analysis involves the regression equations derived for each method, which predict safety factors based on depth, width-to-height ratio of the pillar, and other mining conditions. These formulas are critically analyzed to determine their reliability and applicability in real-world mining scenarios, addressing the specific requirements of safety as mandated by Indian mining regulations and the practical conditions encountered in the field.

The study aims to bridge the gap between theoretical models and their practical application, providing valuable insights that could lead to more effective and safer mining practices. Through this comparative analysis, the research not only underscores the variations in predicted safety factors across different methods but also suggests improvements in the existing models to enhance their predictive accuracy and utility in mine planning and design.

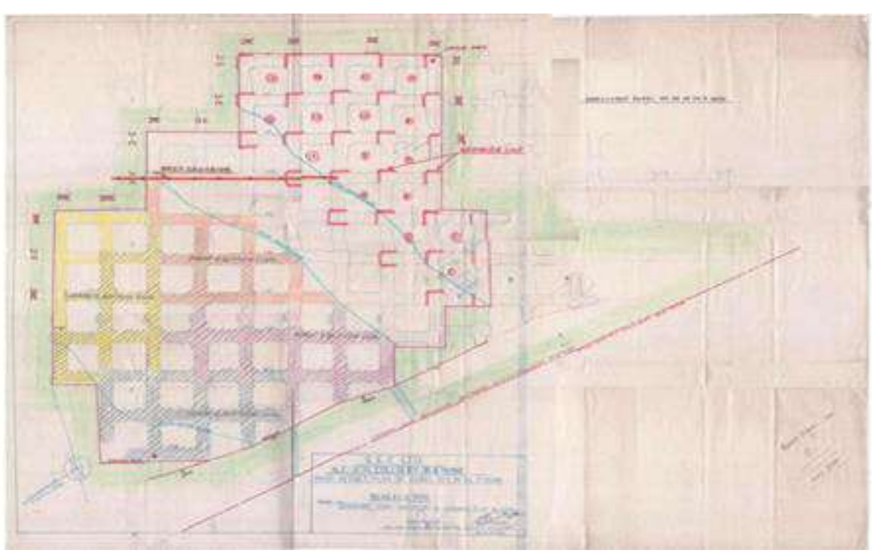

**Figure-2:** Part plan of investigation panel S-1, R-6 mine site

## LITERATURE REVIEW

The design of mine pillars remains a focal point of research in mining engineering due to its critical role in ensuring the safety and structural integrity of underground mining operations. Historically, several methodologies have been developed and refined to predict the stability and performance of mine pillars under varying geological and operational conditions. This review explores significant contributions in the field, focusing on three predominant methodologies: the CMRI, Bieniawski, and Obert-Duvall approaches.

1. **Central Mining Research Institute (CMRI) Method:** The CMRI method, often employed in Indian mines, utilizes empirical formulas to calculate the safety factors of pillars based on specific mining conditions (Singh et al., 2003). This method has been widely recognized for its tailored approach to the geotechnical properties prevalent in Indian coal mines, offering a balance between safety and economic extraction (Mishra and Das, 2010).
2. **Bieniawski's Method:** Developed by Z.T. Bieniawski in the 1970s, this methodology provides a formulaic approach based on extensive case studies and mining operation analyses worldwide (Bieniawski, 1976). It is renowned for its application in a variety of geological settings, allowing for adjustments based on empirical data and providing a robust framework for pillar design (Kumar and Deb, 2014).
3. **Obert-Duvall Method:** The Obert-Duvall method, derived from extensive field data and laboratory testing, emphasizes the role of width-to-height ratio and depth of cover in determining the stability of a pillar (Obert and Duvall, 1967). This approach has been particularly useful in assessing the safety factors in deeper mining operations, adapting to the increasing stresses encountered at greater depths (Li and Peng, 1992).

Recent studies have sought to integrate these traditional methods with modern computational tools and statistical models to enhance predictive accuracy and reliability. For example, regression analysis and machine learning techniques have been applied to refine the safety factor calculations and adapt them to complex mining conditions (Chen et al., 2018). These advancements underscore the dynamic nature of mine pillar design, highlighting the need for continuous evaluation and adaptation of existing models.

Moreover, the implementation of these methods in the field has revealed discrepancies between theoretical predictions and actual performance, often attributed to varying geological conditions and operational practices (Nelson et al., 2016). This has led to calls for more comprehensive models that incorporate a wider range of variables, including material heterogeneity and real-time monitoring data (Jones et al., 2020).

The literature consistently indicates that while each method provides valuable insights, there remains a substantial scope for improvement in terms of integrating more accurate geotechnical data and real-world mining conditions into the design process. This study builds on the existing knowledge base, aiming to critically analyze and compare the effectiveness of these methods in predicting pillar stability in Indian coal mines.

## METHODOLOGY:

This research employs a comparative analysis approach to evaluate and contrast the effectiveness of three widely used pillar design methodologies (CMRI, Bieniawski, and Obert-Duvall) in predicting the safety factor of mine pillars under varying conditions prevalent in Indian underground coal mines. The study is structured to assess each method's applicability and accuracy through a series of empirical validations and regression analyses. The following steps outline the methodology used in this study:

**1. Data Collection:** Data for this analysis was primarily sourced from operational records of several underground coal mines across India. Parameters such as mining depth, pillar dimensions (width and height), gallery opening widths, and geological conditions were collated. Historical data regarding pillar performance and failure incidents were also included to provide a comprehensive basis for analysis.

**2. Application of Pillar Design Formulas:** For each collected data set, the safety factors were calculated using the formulas prescribed by the CMRI, Bieniawski, and Obert-Duvall methods. This process involved inputting the respective variables into each formula to determine the theoretical safety factors under specified conditions.

**3. Regression Analysis:** To refine the predictive power of each method, regression analysis was conducted on the outcomes obtained from the theoretical calculations. This step involved deriving new regression equations that could more accurately predict safety factors based on observed data. The regression models were validated through a statistical approach, assessing the R^2 values to determine the fit of the model to the data.

**4. Comparative Analysis:** The results from the regression models were then compared to ascertain the relative effectiveness of each method in predicting pillar stability. This comparison focused on:

- The accuracy of safety factor predictions at various depths and pillar dimensions.
- The responsiveness of each method to changes in mining conditions.
- The practical applicability of each method in terms of ease of use and reliability in the field.

**5. Validation with Real-World Data:** The newly derived equations were further tested against a set of real-world mining operations not included in the initial data set. This validation aimed to test the robustness and generalizability of the regression models under diverse mining conditions.

**6. Sensitivity Analysis:** A sensitivity analysis was conducted to examine the impact of variations in key parameters (e.g., mining depth, width-to-height ratio of the pillar) on the predicted safety factors. This analysis helped identify critical thresholds beyond which the predicted safety factors would fall below acceptable safety standards, as per Indian mining regulations.

**7. Assumptions and Limitations:** The study acknowledges certain assumptions, such as uniform material properties and consistent operational conditions across different mine sites. The limitations concerning geological variability and operational discrepancies are also

**RESULTS AND DISCUSSION:**

The comparative analysis of the CMRI, Bieniawski, and Obert-Duvall methods revealed distinct variations in the predicted safety factors under similar conditions, which are critical for designing stable mine pillars. The regression analysis results are summarized below:

- **CMRI Method:** This method consistently predicted higher safety factors across various depths and pillar dimensions, with an R^2 value of 0.980, suggesting a strong predictive accuracy within the model's scope. For instance, at a mining depth of 200 meters, the CMRI approach showed a safety factor variation from 2.78 to 3.60, which is above the minimum required safety factor of 1.5 as per Indian mining regulations.
- **Bieniawski Method:** The predicted safety factors using this method were generally lower, with safety factors ranging from 0.70 to 1.35 at the same depth, indicating a potential underestimation of pillar stability. This method's R^2 value was 0.926, indicating a good but slightly lesser fit compared to the CMRI method.
- **Obert-Duvall Method:** This approach yielded moderate safety factor predictions, which were more conservative than CMRI but less so than Bieniawski. It showed a maximum safety factor of 4.187 at a depth of 150 meters for a specific width-to-height ratio, aligning more closely with realistic and safer mining practices.

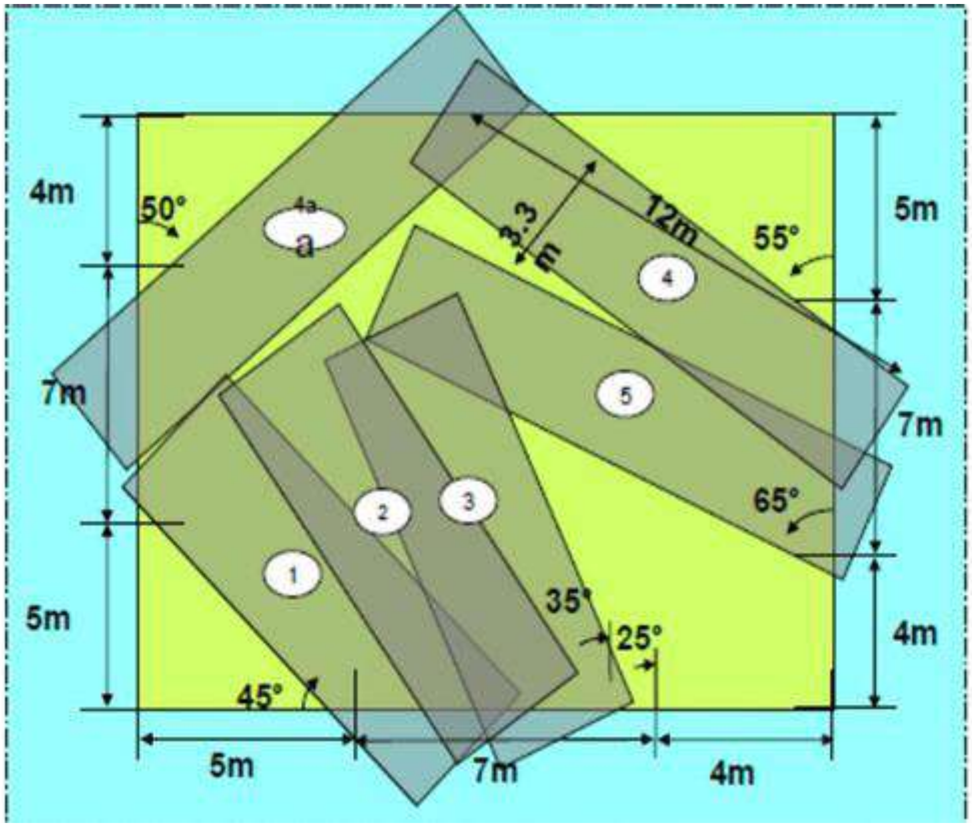


**Figure- 3:** Pillar Extraction-Slicing Sequence with dimensions

## DISCUSSION

The findings suggest that while the CMRI method may offer overly conservative estimates leading to potentially reduced extraction efficiency, the Bieniawski method might risk underestimating the necessary safety margins, potentially compromising pillar stability. The Obert-Duvall method appears to provide a balanced approach, aligning better with actual conditions in Indian mines.

The discrepancies between methods underscore the necessity for mine operators to consider multiple approaches and adapt pillar design formulas based on specific mine conditions and regulatory requirements. Moreover, the variations in R^2 values indicate the importance of choosing a method that best fits the geological and operational complexities of a mine.

The sensitivity analysis further highlights the critical impact of depth and pillar dimensions on safety factors, affirming the need for dynamic modeling that incorporates real-time data and variable mining conditions to optimize pillar designs effectively.

## CONCLUSION

This study critically evaluated the CMRI, Bieniawski, and Obert-Duvall methods for designing mine pillars, highlighting significant differences in their predictive capabilities and implications for mine safety. The regression models developed through this analysis offer improved predictability and can serve as robust tools for mine planners and engineers seeking to optimize safety and efficiency.

However, the study's limitations, including assumptions about uniform material properties and operational consistency, suggest the need for further research incorporating a broader range of data, including material heterogeneities and real-time monitoring outputs.

## RECOMMENDATIONS:

1. Future studies should aim to integrate more comprehensive datasets, including varying geological conditions and operational discrepancies.
2. Development of hybrid models that combine the strengths of existing methodologies could potentially offer more accurate predictions.
3. Implementation of real-time monitoring technologies to dynamically adjust pillar designs in response to changing mine conditions.

In conclusion, while each method provides valuable insights into pillar stability, a hybrid approach tailored to specific mine conditions and continuous data integration may enhance safety outcomes in underground coal mining operations.

## REFERENCES

1. Alan, A., Campoli, Carla, A. Kertis, and Claude A. Goode. (1987): Coal Mine Bumps: Five Case Studies in the Eastern United States. Information Circular (IC-9149), Bureau of Mines.
2. Banerjee G., Kushwaha A., Kumbhakar D. & Sinha A., (2007), Prediction of Strata and Support and Support Behavious during Shortwall Mining of Developed Bord and Pillar Workings at Balrampur Mine, SECL, Proc. Of National Seminar on Mining TechnologyPresent and Future 21-22 September 2007, Bhubaneswar.
3. Bieniawski, Z.T., (1989), “Engineering Rock Mass Classification—a Complete Manual For Engineers and Geologists in Mining Civil and Petroleum Engineering”, Wiley and Sons, New York.
4. BIS, (1985). BIS: 11309 (Indian standard method for conducting pull-out test on anchor Bars and rock bolts). Bureau of Indian Standards, N. Delhi.
5. BIS, (1992). BIS: 11517 (Rock Bolts – Resin Type – Specification). Bureau of Indian Standards, N. Delhi. Pp-2.
6. British Coal, (1992), Code of Practice 01/30, “The Support of Mine Roadways by Rock Bolts.”
7. B.S., (1996).Guidance on the use of rockbolts to support roadways in coal mines. DeepMines Coal Industry Advisory Committee, Health and Safety Commission.
8. Cannbulat, I. and van der Merwe, J.N., (2000). Safe mining face advance and support Installation practice in mechanical miner workings under different geotechnical Conditions. SIMRAC Report, COL 609.
9. CMR. The Coal Mines Regulations 1957. (ed.), (2000), L.C. Kaku, Lovely Prakashan, Dhanbad.
10. CMRI Report, (1987), Development of roof supports for mechanized bord and pillar Working and fast drivage and their field evaluation, S&T Project Report.
11. CMRI Report, (1987b), (unpublished), Geomechanical classification of coal measure Roof rocks vis-à-vis roof supports.
12. CMRI Report. (1997) “Mechanised depillaring of thick seam standing on pillars at NCPH Mine with cable bolts as high roof support”, (Unpublished) S&T report.
13. CMRI Report (unpublished) (2003): Strata behaviour study during depillaring with Continuous miner and shuttle car at Anjan Hill Mine, Chrimiri Area, SECL,
14. CMRI Report (2007)., Development of Support Guidelines For Depillaring Panels In Indian Coal Mines, report of the project funded from Coal S&T grant of Ministry of Coal, Govt. of India May 2007.
15. Cullen, M., (1989), “Rock Bolt Quality Assurance at the Myra Falls Mine” Westmin Resources Ltd. Internal notes for short course.

16. Cullen, M., (2002). “Geotechnical Studies of Retreat Pillar Coal Mining at Shallow Depth:, Ph.D. Thesis, University of British Columbia.

17. DGMS Circular, Tech. (Sapicom), 3 of 1993 and 6 of 1996

18. DGMS, (2012), Annual reports and circulars from Directorate General of Mines safety, India, 1975 to 2012.

19. Dikshit, M. P. (2010): Underground mining in India: Prospects, Problems and Innovations. Proc. Of 3rd Asian Mining Congress – Resurgence of mining in Asia: Prospects and challenges (editors: L.K. Bose, B.C. Bhattacharya and G.P. Ghatak), Vol. I, MGMI, Kolkata, India, 22-25 January.

20. Esterhuizen, G.S. (2000), “Jointing Effects on Pillar Strength”, Proceedings: 19th International Conference on Ground Control in Mining, Morgantown, West Virginia, August 2000.

21. Follington I.L., Trueman, R., Medhurst, T.P., Hutchinson, I.N. (1992). Continuous Monitoring of mechanized breaker line supports to investigate roof and pillar behavior. In: Proceedings of the 11th International Conference on Ground Control in Mining. Wollongong, New South Wales, Australia: University of university.