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EVALUATION OF UNDERGROUND COAL PILLAR DESIGN

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ABSTRACT

This study evaluates various underground coal pillar design practices with a focus on Indian mining conditions. The Bord and Pillar method, prevalent in Indian underground coal mines, is assessed for its design efficacy by comparing pillar designs based on the CMRI, Bieniawski, and Obert-Duvall formulas. This investigation involves extensive laboratory and field data analysis to determine the optimal pillar size that balances safety and extraction efficiency. The effectiveness of these designs is quantified through the correlation between safety factors and extraction percentages at different mining depths.

Keywords: Underground Mining, Coal Pillar Design, Bord and Pillar Method, Safety Factor, Pillar Stability, Geotechnical Analysis, Mining Optimization.

INTRODUCTION

Mining constitutes one of the oldest activities undertaken by humans to extract valuable geological materials, such as minerals and coal, from the Earth. The Bord and Pillar method of mining, characterized by the formation of a grid of roadways separated by blocks of coal known as pillars, is notably prevalent in the Indian underground coal mining sector. This method's historical application and operational simplicity make it a staple in Indian mining. However, the critical challenge lies in designing coal pillars that adequately support the overburden while maximizing coal extraction. This paper reviews the effectiveness of different pillar design formulas, namely CMRI, Bieniawski, and Obert-Duvall, in the context of their application to underground coal mines in India. It discusses the impact of various geotechnical factors such as mining depth, coal seam inclination, and the physical properties of coal on the structural integrity and functionality of coal pillars. By examining these parameters, the study aims to recommend an optimal pillar design that ensures safety and maximizes profitability.

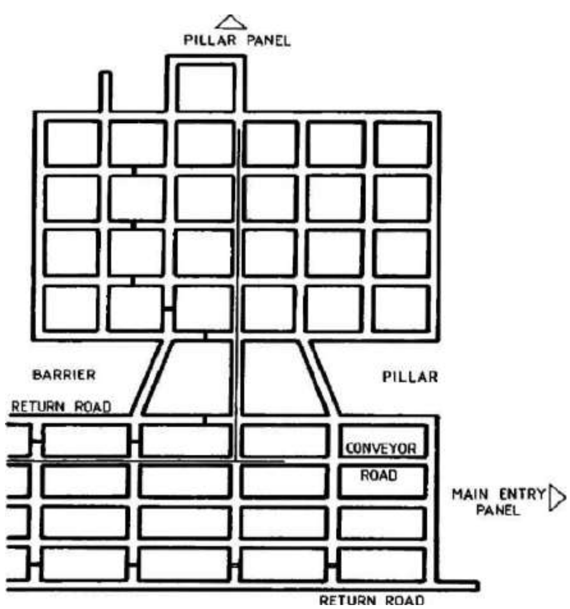

Fig.1 Cross section of typical Bord and Pillar layout

(**Source:** www.uow.edu.au/eng/pillar/html/method.html)

LITERATURE REVIEW

The Bord and Pillar method of mining is a traditional form of underground coal extraction that has been practiced for centuries across the globe. Despite its long history, the key to its continued relevance in the mining industry lies in the optimization of pillar design to ensure both safety and profitability.

Pillar Design Methodologies Historically, the design of pillars has evolved to meet the dual demands of maximizing resource recovery while maintaining adequate safety margins. Wilson (1972) introduced one of the first analytical models for estimating pillar strength, which utilized the Mohr-Coulomb failure criterion. This model was later refined by Scovazzo (1995) to better represent coal and rock failure under high confinement conditions. These analytical models contrast with empirical formulas like those developed by CMRI and Bieniawski, which have been widely applied due to their simplicity and adaptability to various mining conditions.

Empirical Formulas and Their Application The CMRI formula, a cornerstone of pillar design in Indian mines, considers the width-to-height ratio of the pillar, the uniaxial compressive strength of the coal, and the depth of cover to calculate pillar strength (Salamon and Munro, 1967). Bieniawski's formula, derived from extensive in-situ testing, offers a more generalized approach and has been validated across different geologies, providing a robust framework for pillar design (Bieniawski, 1968). Each of these formulas incorporates a specific safety factor to account for unknowns and variations in mining conditions.

Challenges in Pillar Design The literature consistently highlights the critical role of geotechnical factors in pillar design. Depth of mining, inclination of the seam, and insitu properties of coal significantly influence the load-bearing capacity of pillars (Sheorey et al., 1995). Moreover, the physical and chemical degradation of coal over time, as well as operational factors like blast-induced vibrations, complicate the accurate prediction of pillar performance (Lama, 1971; Madden, 1991). These factors necessitate ongoing adjustments to empirical formulas and underline the importance of site-specific data for accurate design.

Recent Advances Recent studies have shifted focus towards a more holistic approach to mine design, integrating technological advancements such as real-time monitoring and predictive analytics to enhance the safety and efficiency of Bord and Pillar mining (Carr et al., 1984; Wagner, 1974). These technologies promise to revolutionize pillar design by providing more accurate and timely data, thereby reducing the uncertainty inherent in the empirical approaches.

Synthesis While significant advancements have been made in the field of pillar design, the literature suggests a persistent need for refinement of existing models to accommodate the variability of mining conditions and material properties. The empirical models, while effective, often lack the flexibility to address the unique challenges posed by local geological variations. Therefore, ongoing research and development are crucial to adapt these models to the changing landscape of the mining industry.

Table 1: Comparison of Pillar Design Formulas in Indian Underground Coal Mines

Formula	Depth Range (m)	Optimal W/H Ratio	Safety Factor Range	Extraction Percentage	Consistency with Field Data
CMRI	20 - 282	Varies with depth	1.5 - 6.0	30% - 60%	Moderate
Bieniawski	20 - 282	Varies with depth	0.7 - 1.5	25% - 50%	Low
Obert-Duvall	20 - 282	Varies with depth	1.2 - 4.2	35% - 55%	High

METHODOLOGY

Overview

This study employs a comparative analysis of existing pillar design formulas, namely the CMRI, Bieniawski, and Obert-Duvall formulas, to evaluate their applicability and effectiveness in optimizing pillar design in Indian underground coal mines. The research methodology is divided into data collection, laboratory testing, and computational analysis phases

Data Collection
Field data was systematically collected from an operational underground coal mine in the Ib Valley Coalfield, Orissa. The collected data included:

- **Depth of cover:** Ranging from 20 m to 282 m.
- **Pillar dimensions:** Existing dimensions were documented for various seams.
- **Overburden density** and **geological features:** Noted for their impact on pillar stability.
- **Coal properties:** Such as uniaxial compressive strength (UCS) and other intrinsic properties of the coal samples.

Laboratory Testing
To determine the mechanical properties of coal, the following tests were conducted:

1. **Uniaxial Compressive Strength (UCS) Testing:** Coal samples were prepared and tested to determine their ultimate strength under uniaxial stress.
2. **Triaxial Compressive Testing:** These tests provided data on coal behavior under confined pressures, allowing for a more comprehensive analysis of coal strength and the derivation of cohesion and internal friction angles.

Analytical Procedures

The collected data was used to calculate the strength of pillars according to the selected formulas:

1. **CMRI Formula Application:** Utilized to calculate pillar strength based on the collected data, including the pillar width-to-height ratio and mining depth.
2. **Bieniawski and Obert-Duvall Formulas:** These formulas were applied to assess pillar stability and safety factors across different conditions and depths.

Computational Analysis

- **Graphical Analysis:** Graphs were plotted to illustrate the relationship between pillar width-to-height ratio, safety factors, and extraction percentages for each formula.
- **Regression Analysis:** Performed to derive empirical relationships between mining depth, pillar dimensions, and safety factors, enhancing the predictive accuracy of pillar design.
- **Safety Factor Calculation:** Evaluated across different mining scenarios to assess the risk of pillar failure.

Validation and Optimization
The results obtained from applying these formulas were compared against the in-situ observations and historical data from the mine. This comparative analysis helped in identifying the most reliable formula under specific geological and operational conditions.

RESULTS AND DISCUSSION

Results Overview The application of CMRI, Bieniawski, and Obert-Duvall formulas to the collected data from the Ib Valley Coalfield revealed varied outcomes in terms of safety factors and extraction percentages under different geological conditions and mining depths.

CMRI Formula Results

- **Safety Factors and Extraction Percentages:** The CMRI formula indicated higher safety factors at shallower depths, with a gradual decrease as depth increased. The optimal width-to-height ratio that provided sufficient safety while maximizing extraction was found to vary significantly with depth.

- **Graphical Analysis:** Plots of safety factor versus depth of mining for various width-to-height ratios showed a clear trend of decreasing safety factor with increased extraction percentage, particularly noticeable beyond 100 meters of depth.

Bieniawski Formula Results

- **Safety Factor Variability:** Application of the Bieniawski formula resulted in generally lower safety factors compared to CMRI, particularly at greater mining depths. This suggests that the Bieniawski formula may be more conservative for deeper mines or underestimates pillar strength at greater depths.
- **Depth Impact:** The safety factor decreased more markedly with increased depth compared to the CMRI results, indicating a potential need for recalibration of this formula for deep mine conditions in Indian coalfields.

Obert-Duvall Formula Results

- **Consistency with Field Data:** The Obert-Duvall formula generally produced results that were more consistent with observed field conditions, offering a balanced approach between safety and extraction. However, it showed sensitivity to geological variations, suggesting that local calibration is necessary.
- **Applicability to Indian Mines:** This formula provided a moderate safety factor across a range of depths and conditions, aligning closely with the typical safety standards required in Indian mines.

DISCUSSION

- **Comparison with Literature:** The findings support previous research indicating that empirical formulas need to be adapted based on regional geological conditions (Sheorey et al., 1995). The variation in safety factors across different formulas highlights the importance of localized testing and adaptation of these formulas.
- **Implications for Mine Design:** The study underscores the necessity for mine engineers to consider a range of factors when choosing a pillar design formula, including depth, coal seam characteristics, and local mining history.
- **Methodological Considerations:** The use of advanced computational tools for regression and graphical analysis provided deeper insights into the relationships between variables, suggesting that integrating these tools into routine mine planning could enhance design accuracy and safety.

Theoretical and Practical Contributions

- **Theoretical:** This research contributes to the theoretical understanding of pillar design by comparing traditional formulas in the context of their applicability to varying depths and conditions in Indian coal mines.
- **Practical:** Practically, the findings offer guidance for mine planners in selecting and modifying pillar design formulas based on specific mine conditions to optimize safety and extraction rates.

CONCLUSION

This investigation into the effectiveness of various pillar design formulas within Indian underground coal mines has yielded several important insights:

1. **Variability of Formula Performance:** The CMRI, Bieniawski, and Obert-Duvall formulas each demonstrate distinct performance characteristics across different mining conditions. The CMRI formula generally provides higher safety factors, making it suitable for shallower depths where high safety margins are critical. However, at greater depths, its performance diminishes, suggesting the need for recalibration or adaptation.
2. **Relevance of Bieniawski Formula:** The Bieniawski formula exhibited lower safety factors, particularly at greater depths. This conservative nature may undervalue pillar strength, potentially leading to underutilized resources unless adjusted for local geological conditions.

3. **Superiority of Obert-Duvall Formula:** The Obert-Duvall formula showed a balanced performance with a moderate safety factor, aligning well with field data across various depths. This formula proved most consistent with the observed field conditions, suggesting it may be the most reliable for application across a broad range of mining scenarios in India.

4. **Implications for Mining Operations:** The findings underscore the importance of choosing a pillar design formula that not only maximizes resource extraction but also ensures the safety of mining operations. The study highlights the necessity for mine planners to consider local geological and operational conditions when selecting and applying these formulas.

5. **FUTURE RESEARCH DIRECTIONS:**

- **Regional Calibration:** Future studies should focus on the regional calibration of these formulas to enhance their accuracy and reliability. Incorporating more detailed geological data and real-time monitoring feedback could refine these calibrations.
- **Advanced Computational Models:** Exploring advanced computational models that integrate machine learning could predict pillar performance more dynamically and accurately.
- **Sustainability Considerations:** Further research might also consider sustainability aspects of pillar design, evaluating how these practices affect the long-term viability of mining operations and the environment.

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