Abstract

Ph.D (Continue)

Investigation into the stability of bord and pillar workings under deep cover

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Abstract

In India, many coal seams have been developed in the form of pillars, but its extraction has become difficult due to geotechnical problems related to the surface or sub-surface constraints leading to huge amounts of coal being locked underground. In this research, a three-dimensional numerical simulation of a complete panel deliberating the distribution of mining-induced stress, the factor of safety of pillar, stook, and rib, plastic zone formation, and roof deformation at higher depth. The induced stress on the rib was found to be 4.65 MPa, which is high enough to crush the rib easily. The pillar's safety factor (FoS) was estimated to be 2.43, sufficient enough to take the overlying load, whereas, for ribs, the Fos of 0.9 signified complete collapse within few days. The plastic zone extended up to 6.1 m in the immediate roof, demanding heavy support to control the roof. Safe working at higher depth using bord and pillar method is only possible with employing backfilling technology to control the strata problem and maximize the coal extraction. Backfilling is considered as a novel idea to improve the factor of safety of left-out coal pillars, consequently leading to improved percentage extraction and minimizing the loss of coal in the left-out workings of the mine. The second section studied the assessment of the impact of sand stowing-based backfill on the peak strength and post-failure behaviour of coal pillars. Rectangular coal samples were prepared and tested with different proportions of sand stowing, and a three-dimensional finite-difference code was used for the numerical simulation (FLAC^{3D} software) to achieve the objective of the study. In laboratory experiments, the proportion of sand stowing was set at 0 %, 60%, 70%, 80%, 90 %, and 100% and tested in a servo-controlled machine, whereas in numerical simulation, the percentage of sand stowing varied from 9% to 91% along with the coal pillar width-to-height ratios ranging from 1.5 to 5. The experimental and numerical results demonstrated that the average pillar strength increased as the proportion of stowing increased. The overall strength increased by 22 % in the experimental study and from 28-32% in numerical simulation. The load vs. displacement characteristic changed from brittle to ductile as the sand proportion increases and the width-to-height ratio increased.

1. Introduction

In India, coal is the primary source of energy resource. As per the Ministry of Coal, 55 % of the country's energy requirement is met by coal. In order to sustainably meet the energy need of India, indigenous development of suitable underground mining techniques and the adoption of innovative technology are critical (Das et al., 2017). Some of the Indian coal mines are developed and are standing on the pillar, but the extraction of the pillar is not possible due to geotechnical challenges such as existing fire, accumulation of gases, subsidence, and several stability problems, which lead to unsafe working and environmental hazards.

In India, bord and pillar method of working is widely used for the extraction of underground coal (Sheorey et al., 1987) where left-out pillars control the mine stability and subsidence. The stability of pillars is critical as it supports the superincumbent strata surrounding the mining void and it also underpins critical surface structures. While working in higher deoth, pillar failure, pillar saplling, roof fall are common and difficult to control. Such conditions often necessitate backfilling technology to strengthen the pillars and prevent their deterioration over time (Fig. 1).

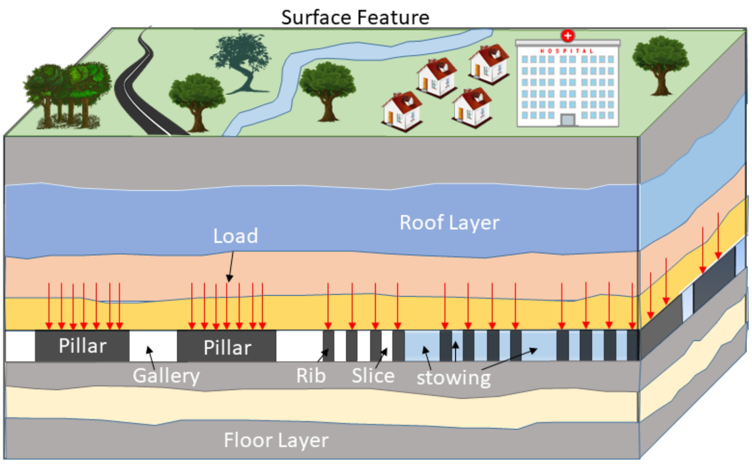

Fig. 1. Conceptual image representing backfilling in goaf to protect surface feature

Backfill is any waste material that is filled into the goaf left over from underground mining operations. Currently, there are several backfill technologies such as hydraulic backfill, rock backfill, high-water material backfill, paste backfill etc. (Cheng et al., 2022). Filling void using any backfill technology is a sustainable approach that can effectively control the load exerted by the superincumbent strata, surface or near surface subsidence, important buildings structure, highways, rivers (Li et al., 2022), pipelines, and reduce the mining operations risk, as well as offer secondary ground support and increased mine worker safety (Zhao et al., 2022).

Preparing paste backfilling materials and transportation to the mine site requires high investment. Also, waste materials like fly ash, tailing, etc., are not readily available across the country; therefore, hydraulic sand stowing is still being used in some of the Indian coal mines to fill the voids created after coal extraction from underground mining. Backfilling technology with sand and water mixture is well established and uses many coal mines to extract the minable deposit at a higher depth of working without disturbing surface or sub-surface structures and minimize any geotechnical problems while extracting coal. It has frequently been stated that even minor confinement provided by backfill increases pillar strength significantly, with the fill material acting in two ways: first, by exerting confining pressure on the pillar sides due to its weight, and second, by providing reaction to the lateral expansion of the pillar.

Therefore, in this research, rectangular coal samples were prepared, and uniaxial compression testing with different proportions of sand stowing was performed in a universal testing machine. The proportion of sand stowing were kept 0%, 60%, 70%, 80%, 90% and 100%. On the other hand, the authors used the three-dimensional finite difference method (FLAC3D) (Itasca Consulting Group, 2019) to simulate the effect of sand stowing on coal pillar strength. W/h ratios ranging from 1.5 to 5 with different proportions of sand stowing were taken, and analyzed the overall strength of the pillar.

2. Results and Discussion

2.1 Stress distribution and propagation of failure zone at higher depth

Three dimensional solid model (Fig. 2) were prepared to simulate the whole panel to understand the state of stress condition and safety factor of the pillar. The dimensions and prporties of the rock material were considered as per the layer formation which obtained from lab testing of the NX size core samples. From the numerical modeling, it was found that the ribs' safety factor is approximately 0.9, which is relatively less stable for only a few days. Therefore, it is not advisable to reduce the rib size during retreat without backfilling. The average vertical stress on pillars, and stooks was estimated using numerical modeling, and the average mining-induced stress on ribs of size 20.2 m × 2.3 m was estimated to 4.65 MPa, which is high enough to crush the rib. To understand the overall stability of the panel, plastic zone were plotted after development and depillaring. The depth of the plastic zone in the side of the pillar was found to be 2.4 m. However, a large portion of coal is left intact, which provides sufficient support to the strata. The plastic zone developed in the immediate roof at the junction of the original gallery extended up to 6.1 m which requires heavy support.

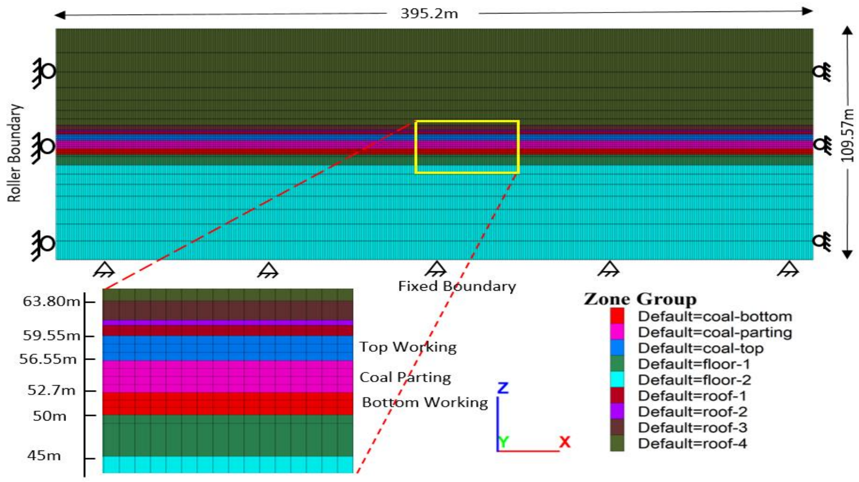

Figure 2: Three-dimensional model preparation in FLAC3D

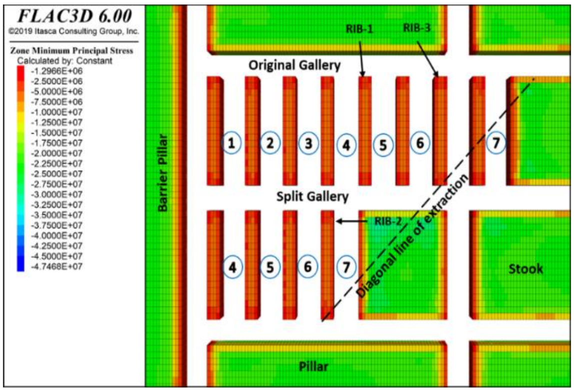

Figure 3 Principal stress distribution on rib and coal pillar during depillaring

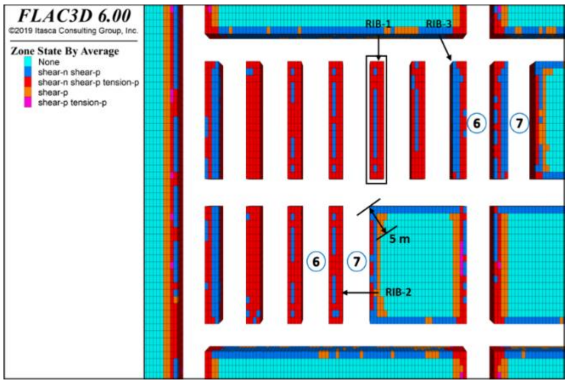

Figure 4 Propagation of failure zone in rib and pillar during depillaring

2.2 Experimental and numerical assessment of the influence of sand stowing on coal pillar strength

The effect on peak strength and post-failure behavior of pillars with different proportions of sand stowing was investigated by laboratory testing and numerical simulation in FLAC3D. Authors found that numerical method tools considerably help to understand the complicated behaviour of coal pillars, including plastic zone. Ninety-six models with different with-to-height ratios ranging from 1.5 to 5.0 and sand stowing proportions varying from 9% to 91% were investigated. A laboratory test was conducted with 60 %, 70 %, 80 %, and 100 % of sand stowing proportion, and the results revealed similar peak strength increments with increases in the proportion of sand stowing. Multiple split failure pattern was observed in the testing sample; however, the intact core within the sample was found to increase as the proportion of sand stowing increased.

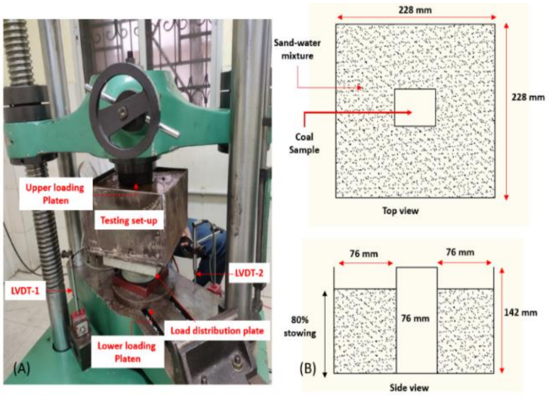

Figure 5 Experimental set up for compression testing with sand stowing

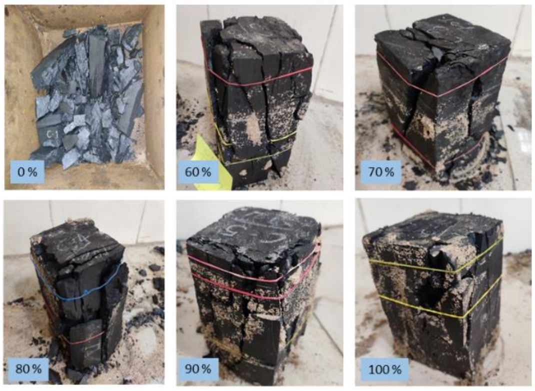

Figure 6: Rectangular coal sample failure state after compression

3. Conclusion

Numerical investigation of the complete panel at a depth of 525 m revealed that the mining-induced stress is high and coal pillar failure propagation extended high, which is difficult to control without heavy support or backfilling. Assessment of the influence of pillar strength on peak strength increases with the proportion of sand stowing increases. Post failure strength also shows significant increment and changes from brittleness nature to ductile nature as stowing proportion increases. The overall peak strength increased by 28-33 % in numerical simulation. Both studies, such as numerical simulation and laboratory testing, concluded that sand provides a small amount of confinement to the coal pillar, resulting in a significant increment of strength and increasing the confining portion within the coal pillar. Finally, the authors suggested using backfilling techniques to manage strata control issues encountered while extracting coal using the bord and pillar method at a higher depth of cover.

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