# Design of mechanized underground extraction of deep-seated coal seam by continuous miner technology under massive strata and high in-situ stress

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ABSTRACT: A mechanised extraction methodology by continuous miner technology is designed for a deep-seated coal seam under massive strata and high in-situ stress conditions by analyzing the stability of rock mass and the rock burst potential through numerical simulation and field investigation. The coal seam having a horizontal-to-vertical in-situ stress ratio of 2.31, is overlaid by the massive sandstone strata and dolerite sill. 3-D numerical simulation is performed to evaluate the stability of rock mass and accumulation of elastic and plastic energy vis-à-vis strain burst index during different stages of the extraction. The energy-based safety factor approach is applied to identify the failed rock mass in the working places to design the support systems to minimise the failure of surrounding rock mass and the rock burst phenomenon. This paper would help the researchers to extract the highly stressed coal seam under massive strata safely and efficiently.

*Keywords: Rock burst, strain energy, massive strata, support design, in-situ stress, side spalling.*

## 1 INTRODUCTION

The prime stability problems at the time of the exploitation of deep-seated coal reserves by underground mining are high in-situ stress conditions causing in bump/burst viz., strain bursts, pillar bursts, and fault slip bursts (Hedley 1992). When the direction of major principal in-situ stress is parallel to the bedding plane, the likelihood of strain burst in the bedded deposits of coal measure sedimentary rocks increases. It causes shearing among the bedded strata (Wang et al. 2016). The roof experiences shear and compressive stresses while the side wall experiences tensile stress in a roadway due to high horizontal stress. If the uncaved roof strata are more prevalent in the goaf/void during the extraction of the coal pillars, the strain burst further increases. It propagates high stress in the surrounding rock mass and the coal pillars at the abutment zone. With the enlargement of goaved-out areas, the critical limit of the stress state is exceeded in the hard roof, resulting in the caving of the hanging roof. The coal mine bump or burst is caused by the rapid release of energy stored in the coal pillars and the surrounding rock mass as a result of the separation and fall of huge overhanging hard strata. The portions of the overhanging roof further increase if the size of remnant/rib pillars is not optimum. The small-sized remnant pillars result in a violent and uncontrolled collapse of the surrounding rock mass whereas the large-sized remnant/rib pillars inhibit the caving of hard roof strata. Furthermore, the unrestrained caving of competent strata frequently goes to the abutment zone. Consequently, the adequate support system, as well as the optimum design of rib/remnant pillars reduces the occurrence of bump/burst and uninhibited roof collapse during the mining of the coal seam under competent and hard strata. This paper describes one such case study of Churcha mine (RO) of South Eastern Coalfield Limited (SECL), India where a suitable extraction methodology and support pattern are designed by field study and numerical simulation.

## 2 DESCRIPTION OF STUDY AREA

The thick overlying strata and stresses induced during coal seam extraction have caused major instability difficulties at the reorganised (RO) Churcha mine of SECL. To address the instability issue that includes uncontrolled rock mass failure, side spalling and strain burst, a suitable extraction methodology by the continuous miner (CM) technology including support patterns is designed for the 7D panel of Seam-V based on the field investigations and energy simulation approach. The average thickness of the seam is 3.4m having an inclination of $3.18^0$ along the direction N43°W. The roof consists of sandstone of medium grain size, having rock mass rating (RMR) of 64, RQD of more than 75%, and cavability index of 10462.78, which fall under "cavable with substantial difficulty" type of strata (Singh 2015). A 113 m thick strong dolerite sill exists 133 m above the roof level of Seam-V. Due to the high cavability index, the formation of hanging goaf is observed during the depillaring operation due to difficulty in caving. The value of major horizontal, minor horizontal and vertical in-situ stresses are found to be 24.29 MPa, 12.01MPa and 10.5 MPa respectively. The measured major horizontal in-situ stress is found to be 2.31 times the vertical in-situ stress at the working depth cover of 420m. The T-split method of pillar extraction is adopted as shown in Figure 1 where two split roadways are driven perpendicular to each other. Slice galleries are driven to extract the fenders by leaving rib/remnant pillars as shown in Figure 1.

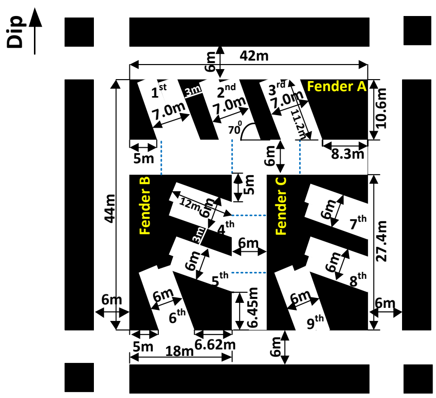


Figure 1. Extraction methodology of a coal pillar (after Das et al. 2023).

## 3 NUMERICAL MODELLING STUDY

A 3D numerical modelling by FLAC3D, Itasca (Itasca 2015) is used to investigate the rock mass stability vis a vis potentiality of strain burst and the support system to be required during the mining of the coal seam. Sheorey's rock mass failure criterion is used to convert the intact rock properties to rock mass properties for successful numerical simulation of field conditions at the site (Sheorey 1997, Das et al. 2023). The equivalent Mohr-Coulomb parameters are calculated from the non-linear failure criterion. The elasto-plastic Mohr-Coulomb constitutive model is used for the overlying and underlying rock strata and the coal seam is simulated by the Mohr-Coulomb strain-softening (MCSS) model. In this study, Sheorey's pillar strength formula (Sheorey 1992) is used to calibrate the MCSS parameters of coal whereas Salamon's formula (Salamon 1984) is used to calibrate goaf materials. Figure 2 shows the grid used in numerical modelling. The safety factor is calculated by the following equation (Das et al. 2023):

$$SF = \frac{Energy\ at\ peak\ stress\ of\ stress-strain\ curve}{Total\ energy\ at\ present\ stress\ state\ (elastic\ energy + plastic\ energy)}$$

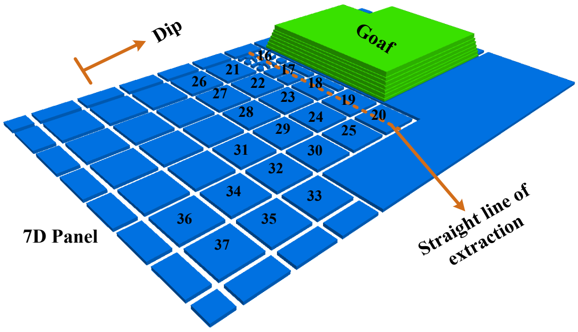


Figure 2. Numerical simulation grid for different stages of working.

## 4 ANALYSIS OF STABILITY FROM THE RESULTS OF NUMERICAL MODELLING

The stability is evaluated during development and the depillaring stages. Figure 3 shows the major principal stress distribution on the coal pillars. The coal pillar experiences an average major principal stress of 13.44 MPa during development and 19.42 MPa during depillaring. By using Sheorey's pillar strength formula, the strength is calculated as 33.68 MPa. As a result, the coal pillar's safety factor is 2.5 during its development phase and 1.75 during its depillaring phase. The safety factor of snook A is calculated as 0.18 at the residual state whereas the safety factor of snook B and C is found to be 0.17 at the residual state after mining the three fenders. Thus, the designed remnant/rib pillars would not prevent the overlying strata from collapsing. The side spalling of coal is observed due to the considerable horizontal stress. It is found from the numerical modelling, that the side spalling extends to 1.5 m inside the coal pillars during the development stage which matches the actual field conditions.

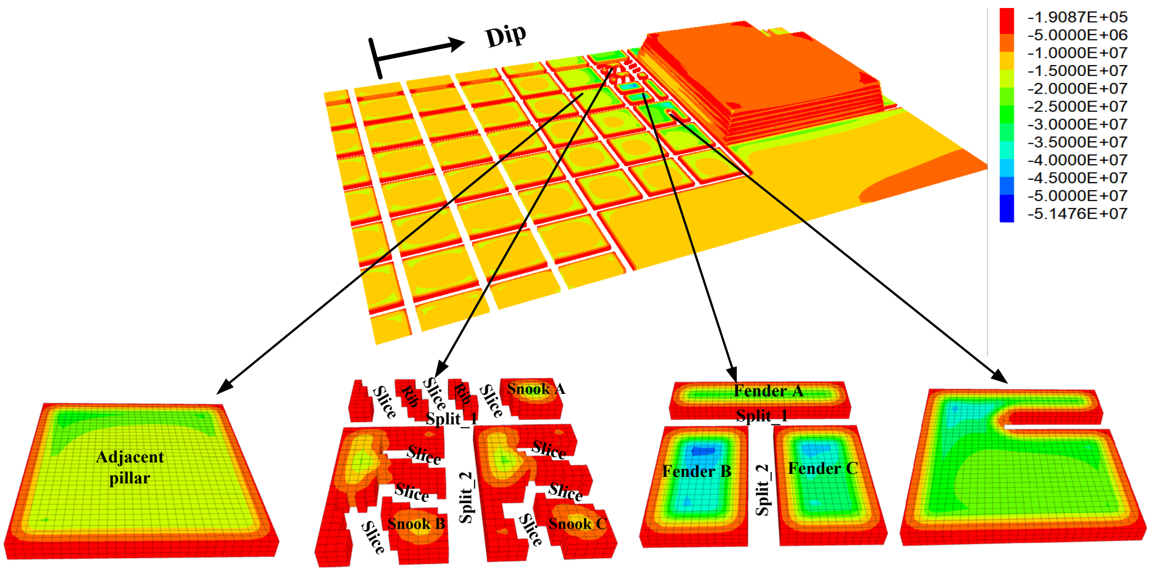


Figure 3. Major principal stress (Pa) acting over the pillar during the extraction.

## 5 ASSESSMENT OF STRAIN BURST POTENTIAL

Castro et al. (2012) proposed an index to quantify the rock burst event based on deviatoric stress which is normalised by the UCS of the intact rock. The index is termed as the brittle shear ratio (BSR) which is expressed by the following equation:

$$BSR = \frac{(\sigma_{1in} - \sigma_{3in})}{\sigma_{ci}}$$

BSR is the brittle shear index, $\sigma_{1in}$ is the major principal stress (MPa) induced due to the excavation, $\sigma_{3in}$ is the minor principal stress (MPa) induced due to the excavation and $\sigma_{ci}$ is the UCS of the intact rock (MPa). The higher value of BSR suggests the more chances of rock burst. Generally, a BSR value less than 0.45 indicates no rock burst condition. The induced major $(\sigma_{1in})$ and minor $(\sigma_{3in})$ principal stresses during the mining of the coal seam are estimated by numerical simulation. As shown in Figure 4(A), the maximum BSR value of 0.68 occurs at a point that is 6.5m distance from the pillar's corner. Due to the high-stress concentration, the corner of the pillar is categorised as a medium rock burst-prone zone. The pillar's side during the development phase is classified as a light rock burst zone. The maximum BSR value in the pillar close to the extraction line ranges between 1.12 and 1.2 during the depillaring stage, as illustrated in Figure 4(B). Therefore, the rock burst and the side spalling are prominent in the original gallery near the extraction line. The highest BSR values in the fender throughout various extraction phases range from 1.4 to 1.57 during the splitting and slicing of a pillar. Thus, significant side spalling and rock burst are witnessed in the split gallery at the time of the slicing operation. The BSR value becomes maximum after the extraction of the Fender A because of the high front abutment load.

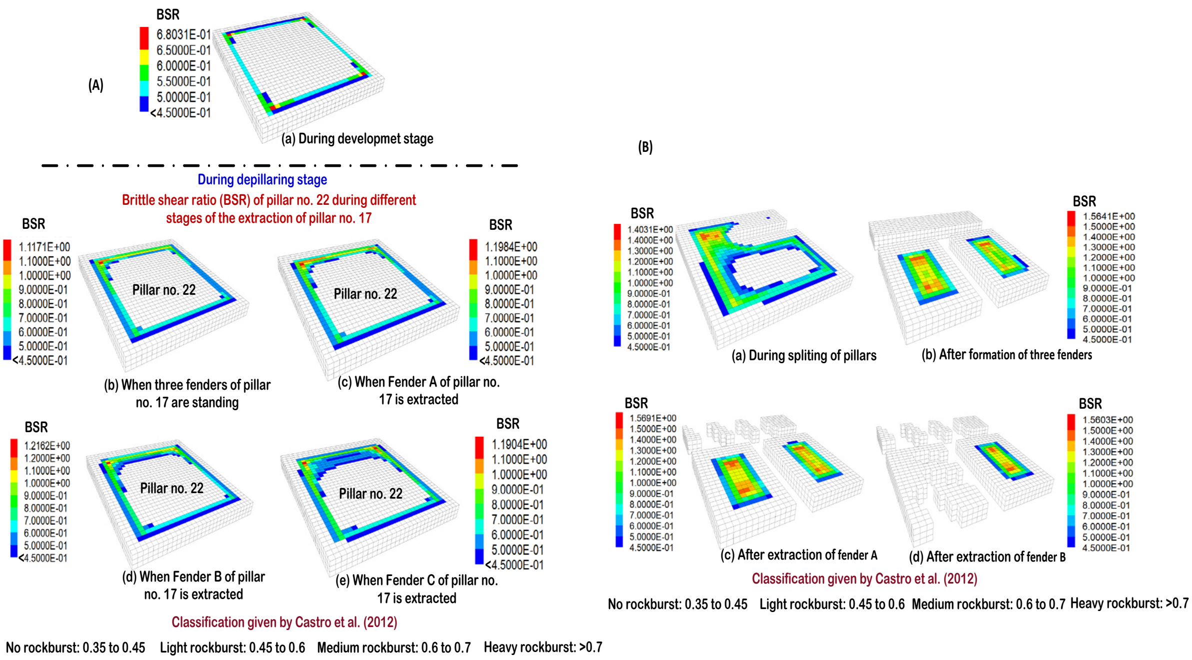


Figure 4. Brittle shear ratio (BSR) of a pillar during (A) development and (B) depillaring stages.

## 6 DESIGN OF SUPPORT PATTERN

The potential failed rock mass ($h_{SF}$) is identified to design support systems for the excavation. In the numerical models, the safety factor values of less than 1.0 are considered as failed zones. The designed support patterns should have adequate support resistance (ASR) to take the load of the potential failed rock mass (P) keeping the support safety factor (SSF) more than 1.0. The support safety factors and support systems for different locations in the depillaring panel are summarized in Table 1 and Figure 6.

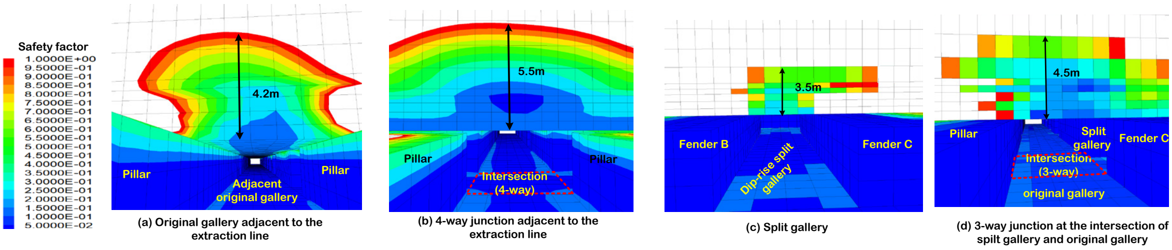


Figure 5. Numerical modelling to identify the extent of yielded rock mass at the roof of (a) split and (b) 3-way junction (c) original gallery and (d) 4-way junction (after Das et al. 2023).

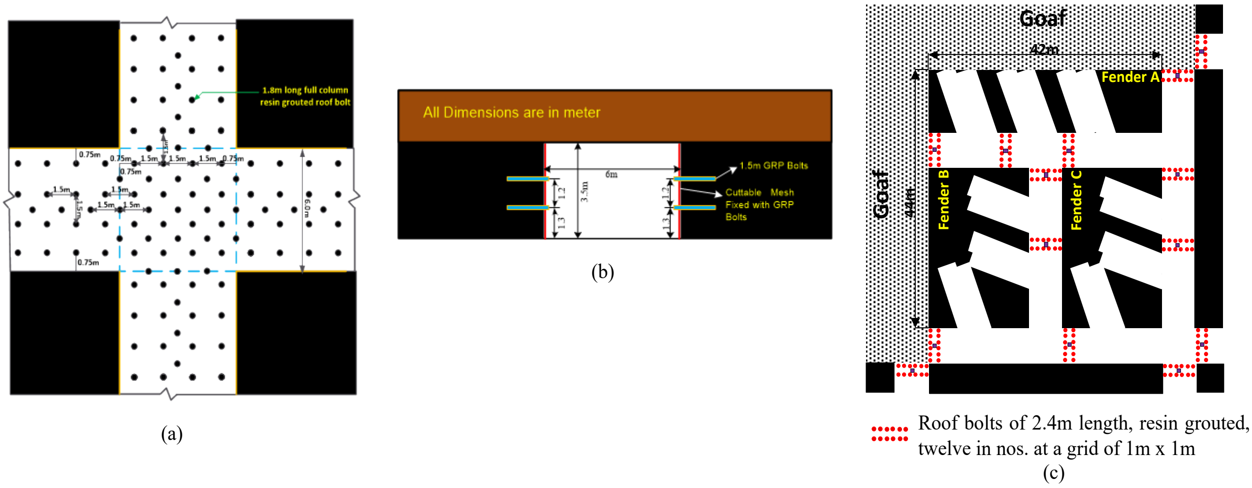


Figure 6. Support system (a) at the original gallery and the 4-way junction, (b) at the side wall of pillar and (c) at the goaf edge.

Table 1: Support safety factors (SSF) for the original gallery, 4-way junction, 3-way junction, split gallery, and for different locations.

| Location | $h_{SF}$ (m) | P (t/m$^2$) | ASR (t/m$^2$) | SSF | Support System |
|---|---|---|---|---|---|
| Original Gallery (6.0m width) | 4.2 | 8.82 | 10.55 | 1.20 | 4 roof bolts in a row of 1.8m long at 1.5m x 1.5m spacing; an additional bolt along the midline between the two rows |
| 4-way Junction (6.0m × 6.0m) | 5.5 | 11.55 | 16.36 | 1.41 | 37 numbers of 1.8m long roof bolts |
| 3-way Junction (at split, 6.0m × 6.0m) | 4.5 | 9.45 | 13.72 | 1.45 | 25 numbers of 1.8m long bolts. |
| Split Gallery (6.0m width) | 3.5 | 7.35 | 10.55 | 1.43 | 4 bolts in a row of 1.8m long at 1.5m spacing; Spacing between the rows is 1.2m. |
| Sides wall of the coal pillar | Two rows of 1.5 m long glass-reinforced plastic (GRP) bolts with a 1.2 m x 1.2 m grid. | | | | |

| | |
|---|---|
| Breaker line | Two rows of 2.4m long bolts in the roof at 1.0m x 1.0m grid |
| Note: Bolts made of cold-rolled TMT/MS M22 threaded ribbed bar with a 22mm diameter that is of full column resin grouted. The density of the rock (immediate roof) is taken as 2.1 t/m$^3$. | |

# 7 CONCLUSION

The energy-based modelling techniques are applied to design the extraction methodology and to assess the rock burst potential of a highly stressed Seam-V of Churcha Mine (RO) under the hard and massive strata. The measured major horizontal in-situ stress is found to be 2.31 times the vertical in-situ stress. Massive sandstone layers that lie above the coal seam are considered to be difficult to cave in during the depillaring phase. It is found that the maximum Brittle Shear Ratio is 0.68 for the development stage and 1.57 during the depillaring stages respectively. It suggests the minor strain burst condition at the coal pillar's sides at the time of the development phase. During depillaring, the substantial strain burst vis a vis the side spalling is deciphered in the split gallery and the original gallery near the extraction line. These findings are validated by field observation and investigation. The T-split extraction methodology has been designed to keep the rib/remnant pillars with a low safety factor so that it does not avert the caving/collapse of the overlying strata. An energy-based safety factor technique combined with numerical modelling is used to determine the amount of the failed rock in order to optimize the support patterns.

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