Analysis of the behaviour of the Barrier Pillars and Gateroads of the deep Longwall Panel of India using the 3D Finite Element Modelling approach

Avula Rajashekar Yadav
Mining Engineering Department, Indian Institute of Technology Kharagpur, India

Sreenivasa Rao Islavath
Mining Engineering Department, Indian Institute of Technology Kharagpur, India

ABSTRACT: In Longwall mining, gateroads play a major role in transporting men and materials and providing ventilation. Barrier pillars lie between two adjacent panels to support the face and gateroads. During the retreating, these gateroads and barrier pillars are subject to mining-induced stresses and may cause the failure of the face, barrier, roof and floor of gateroads. The behaviour of barrier and face must be assessed to extract the panel successfully. For this, a longwall panel of 250 m x 2500 m size lying at 530 m depth is analysed using 3D finite element modelling technique. This study considers the variations in retreat distance, coal properties, and barrier size. All the numerical models are analysed considering Mohr-Coulomb criterion. The vertical displacement in gateroads and stress on the barrier and longwall face, abutment zone and yield zone are analysed, and the safety factor of the barrier pillars and longwall face are determined.

Keywords: Barrier pillar, Gateroad, Development of load, Goaf, Safety factor

1 INTRODUCTION

The longwall mining is proven as the most suitable technique to extract the coal from deep underground mines with safety. The barrier pillars and gateroads that are driven into virgin coal to develop the longwall panels and are required to stand and support the coal excavation operations until the panel is mined. During the retreating, stress develops on the barrier pillars, working face, and neighbouring panels, convergence occurs in the roof and heaving observes in the floor of gateroads and face. As a result, the barrier pillars, face, and gateroads may deteriorate, and lose their stability and may start to yield (Colwell et al., 2003; and G. S. Esterhuizen et al., 2019).

The behaviour of the barrier pillars and gateroads must be required to determine the optimum size of the barrier to extract the coal from deep longwall panel safely and effectively. Several investigations on the behaviour of the barrier pillars, longwall face, and gateroads have been carried out based on theoretical, empirical, and numerical approaches. Most of the study have been conducted by collecting real field data from the mine site (Gearhart et al., 2017; Tulu et al., 2018; and G.Esterhuizen et al., 2019). Shi et al., 2021 conducted the study to determine the roof convergence, stress and abutment zone in the longwall face.

This paper investigates the behaviour of barrier pillars, longwall face, and gateroads by using 3D finite element modelling technique. A longwall panel of India which is 250 m wide and 2340 m long lying at around 530 m depth is chosen for this study. Each finite element model consists of a longwall face, barrier pillars, gateroads, adjacent two longwall panels in which one panel is completely goaved out and another remains virgin, goaf of the working panel, coal seam, and other coal-bearing strata. This research considers variations in coal material properties, barrier pillar size, and retreat distance. The Mohr-Coulomb criteria is chosen to analyse the behaviour of longwall workings. The vertical load development on the barrier pillars and longwall face, and vertical displacement in TG2 and MG2 are estimated for different barrier pillar sizes (50 m,45 m and 40m), material properties (GSI-50, 45 and 40), and retreat distance (100 m,125 m, and 150 m). The yield and abutment zone and safety factor of the barrier pillars and longwall face are estimated.

2 DESCRIPTION OF THE MINE SITE

Adriyala Longwall Project (ALP) of the Singareni Collieries Company Limited (SCCL) is located in the Ramagundam Coal Belt of Godavari Valley Coalfields in Telangana State (India). The depth of coal reserves lies within the depth range of 294–644 m. The study mine comprises the 1, 2, 3, and 4 seams, respectively. Seam 1 is being extracted using longwall technology, and rest seams are virgin. The coal layers in seam 1 are 6.74 m thick, of which 3.2 m are removed by longwall mining. Clay and shaley coal are seen in narrow strips on the overlying roof. The lithology of the mine site is shown in Figure 1. At present panel no. 3 is being excavated. However, this study is conducted on panel 2 which has 250 m wide and 2340 m long. Figure 2 shows the longwall panels developed in the longwall workings. The size of barrier in panel 1 and 2 are 50 m and 63 m respectively.

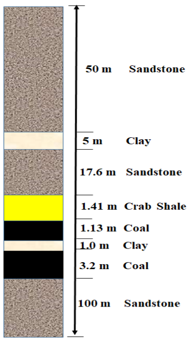

Figure 1. The lithology of the mine.

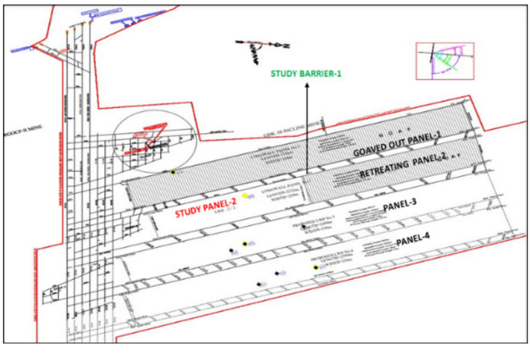

Figure 2. Layout showing ALP mine.

3 DEVELOPMENT OF 3D LONGWALL PANELS TO ANALYSE THE BEHAVIOUR OF BARRIERS, FACE, AND GATE ROADS

A total of 28 three-dimensional numerical models have been developed with the help of lithology collected from the mine site (Figures 1 and 2), which includes 1 insitu model and 27 longwall models. 27 longwall models are developed with varying barrier sizes (40 m, 45 m and 50 m), retreat distance (100 m, 125 m, 150 m) and material properties (GSI 40, 45, 50).

Each longwall model consists of barrier pillars, gateroads, cross cuts, the longwall face, the coal seam, and the surrounding strata (Figure 3). The Mohr's-coulomb failure criterion is used to analyse the finite element models. The study longwall panel is developed with face length of 250 m and 552 m long, and is situated at a depth of about 530 m from the surface. The model has four (4) pillars each for barrier 1and 2 and are designated as BP-1, BP-2, BP-3, and BP-4. The length of these pillars are 100 m, 200 m, 200 m, and 50 m. The size of gateroads and crosscuts are 5.2 m x 3.2 m. In this study, it is assumed that panel no.1 is already excavated and formed as goaf (panel no.1). The barrier 1 is situated in between completely goaved out panel and working panel (panel no.2). To simulate the goaf in the goaved out panel and retreated panel, the height of the goaf is estimated as 29.2 for a bulking factor of 1.2 and mining height 3.2 m (Yavuz, 2004).

Figures 4 (a) and (b) show the discretized model of longwall panels. As shown in Figures, the finer mesh is developed to estimate the displacement, stress and safety factor in the gateroads, barrier pillars and longwall face.

In this study, the 3D FEM model (Figure 4c) is applied with a horizontal pressure of 1.5 times the vertical pressure (20.02 MPa) in the strike direction (Z) and 1 time the vertical pressure (13.348 MPa) in dip (X) directions, respectively. The model is also applied a 9.81 N gravity load in a vertical direction. The opposite faces of Z and X directions are applied constraints in the Z and X directions. The bottom of the model is fixed in all direction. The top of the model is applied 2.10 MPa, which is equivalent to 100 meters of overburden as the overburden layer is considered as 430 m on the coal seam.

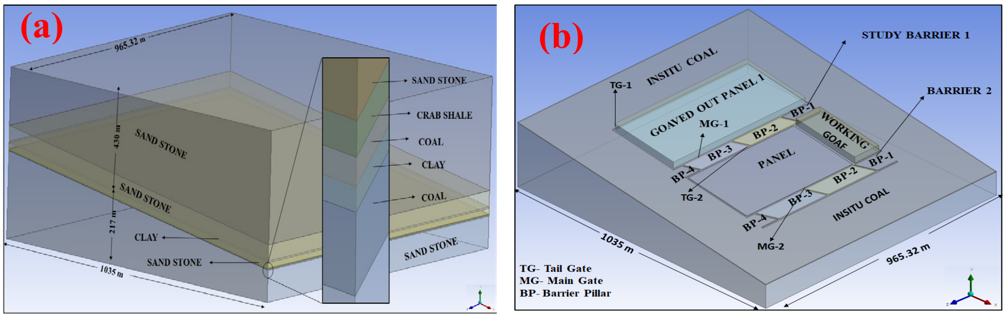

Figure 3. 3D finite element model of a deep longwall panel.

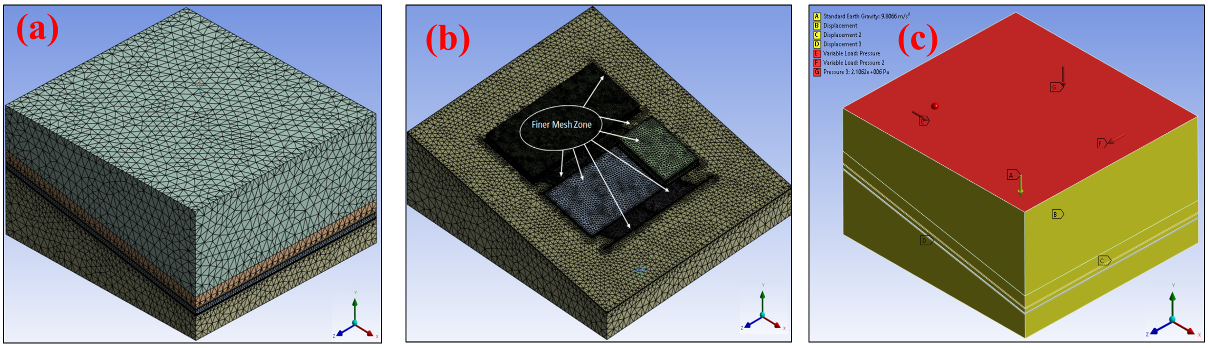

Figure 4 (a). Meshing of the model. 4(b). Finer mesh zone. 4(c). Assigned boundary conditions.

3.1 Rock mass Material Properties

Table 1. Rock mass material properties of coal for different GSI values (Islavath et al., 2016).

Rock strata	Density ρ (Kg/m^3)	Compressive strength σ_c (MPa)	Modulus of elasticity E (GPa)	Poison's ratio (υ)	Cohesion C (MPa)	Friction angle Φ^0	Dilation angle δ^0
Clay	1100	2.582	1.278	0.35	0.811	27	18
Coal	1500	4.13	1.535	0.35	1.00	31	21
Sandstone	2147	7.643	5.132	0.28	1.461	38	19
Carb shale	1276	2.980	1.40	0.35	0.904	28	19

Coal, clay, and sandstone intact rock properties gathered from the mining site and based on RocLab software, rock mass parameters such as compressive strength (σ_c), angle of internal friction (Φ^0), cohesion (C), and modulus of elasticity (E) are evaluated for coal, clay, and sandstone. Assuming GSI of 50, 45, and 40. Disturbance factor (D) is taken as ‘0’ since coal is sliced by a shearer in the longwall face and the gate roads developed by road headers. For coal, clay, and sandstone, the Hoek-Brown parameter m_i is taken as 7, 7, and 10 respectively, Tables 1 list the rock mass properties used for study. Also, the modulus of elasticity (E_G) of a goaf material is estimated based on study conducted (Yavuz, 2004). The partially packed goaf is applied to present retreating panel and fully packed goaf is applied to goaved out panel.

4 RESULTS AND DISCUSSIONS

All the combinations of numerical models are solved considering Mohr’s - coulomb failure criterion. The findings in terms of the vertical displacement in the gateroads, vertical stress on barrier pillars and the panel, and safety factor distribution on barrier and panel are extracted and presented.

4.1 Vertical stress distribution on barrier pillars

The vertical stress distribution on the barrier pillars for various models is extracted and analysed. Figure 5(a) shows the vertical stress distribution profile of barrier 1 for retreat distance 100 m, 125 m and 150 m. Form this Figure, it is noticed that the corners of the barrier pillars are experiencing the maximum stress and that of minimum in the core of the pillars. It is also observed that there is a substantial stress development in barrier pillars 1 and 2 and does not change on pillars 3 and 4 for any retreat distance. This phenomenon has observed for all the combinations of the numerical models. The average stresses on barrier pillars for 100 m retreat distance is found to be 9.20 MPa whereas 9.53 MPa and 10.06 MPa for 125 m and 150 m retreat distance respectively.

Figures 5(b) and 5(c) show the average vertical stress distribution on barrier pillar with varying its size (40 m, 45 m, and 50 m) and change in material properties (GSI 40, 45 and 50) respectively. From this Figure, it can be seen that the development of vertical stress on the barrier pillars reduces with increment of its size. Also reduces with improvement of competence of the barrier pillars.

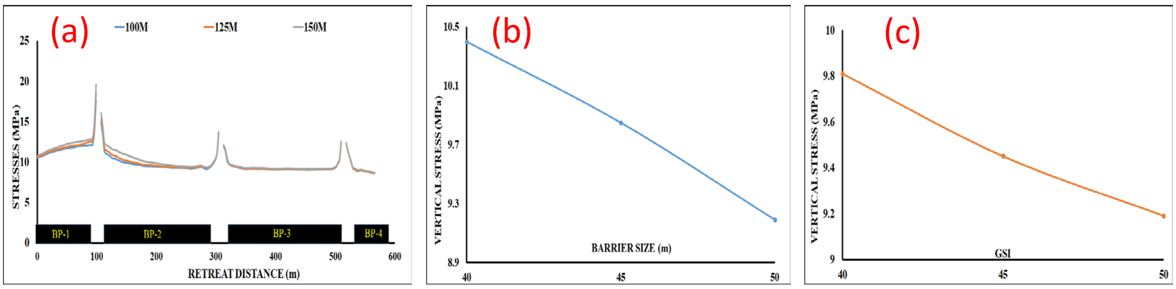

Figure 5 (a-c). Vertical stress distribution on barrier pillars for various retreat distance, barrier size and GSI.

4.2 Vertical stress distribution on longwall face

The vertical stress distribution profiles on the longwall face is taken at the center of the panel moves along the panel length. From the analysis, it is observed that the maximum stress of 25.20 MPa, 30.18 MPa, and 34.26 MPa develops for a barrier sizes of 50 m, 45 m, and 40 m respectively. Also, the stress influence/ abutment zone is found to be between 30 m and 40 m in this study (Figure 6).

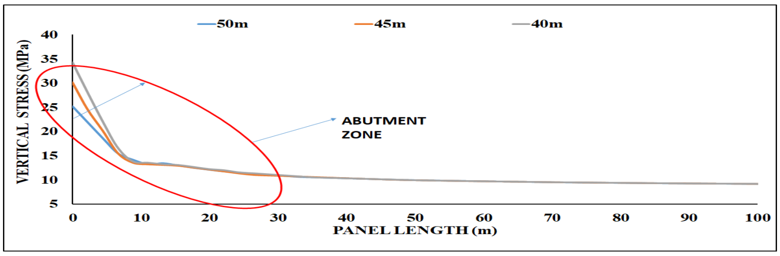

Figure 6. Vertical stress distribution on longwall face.

4.3 Vertical displacement in gateroads

The maximum vertical displacement profile of TG2 and MG2 is extracted for excavation and insitu models for different combinations. Then, the maximum vertical displacement generated due to longwall workings is obtained and analysed. It may here be noted that TG2 lie in the rise side and MG2 lies at dip side. Figures 7 (a) shows the vertical displacement profile of TG2 for various retreat distance. It is found that maximum vertical displacement of 46 mm, 53 mm and 58 mm in TG2 for retreat distance of 100 m, 125 m, and 150 m respectively. Similarly, for MG2, 57 mm, 82 mm and 105 mm occurs for retreat distance of 100 m, 125 m and 150 m respectively. The low displacement in TG2 is observed since this gate exists at the rise side.

As shown in Figures 7(b) and (c), it is found that the development of vertical displacement reduces with the increment of competence and increases with increment in retreat distance. Similarly, it reduces with increment in pillar size.

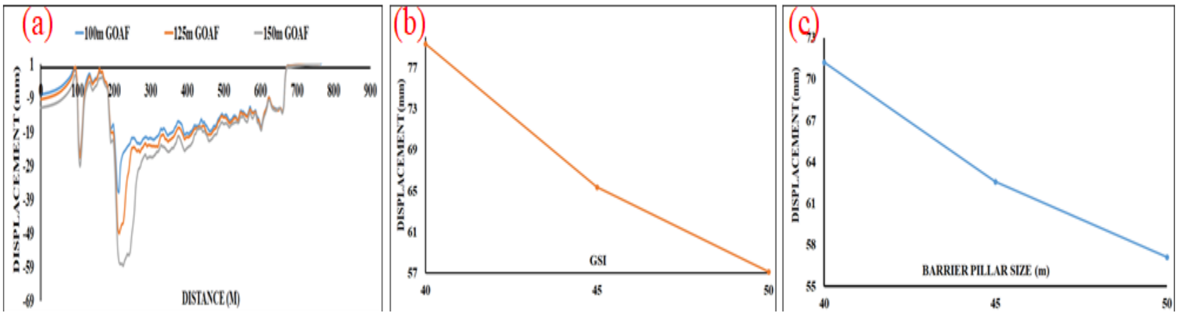

Figure 7. Vertical displacement profile on TG2 for retreat distance and MG2 with pillar and GSI variation.

4.4 Factor of Safety of the Barrier Pillars and Longwall face

As mentioned above using the Mohr's-Coulomb rock mass failure criteria, the safety factor of the barrier pillars and the longwall workings are determined (Equation 1).

$$FOS = S_p/\sigma_p = \frac{\sigma_3 N_\emptyset + 2c\sqrt{N_\emptyset}}{\sigma_1} \quad (1)$$

A barrier pillar/working panel is considered to be safe if FOS is greater than 1.5; where σ_1 and σ_3 are major and minor principal stress, $N_\emptyset$ is the triaxial factor and c is cohesion, and $\emptyset$is the angle of internal friction of the coal.

Figures 8(a) and (b) show factor of safety on barrier pillars and the longwall face for different retreat distances respectively. From Figures 8 (a), it is observed that the average safety factor of pillar 2 of 1.88, 1.84, and 1.82 for retreat distance of 100 m, 125 m, and 150 m respectively. Also on the longwall face, it varies from 2.36 to 2.27 (Figure 8b). From the results it is concluded that the safety factor increases with increase in barrier size and competence of coal/pillar and reduces with retreat distance. It can be clear from this Figure that the corners of the barrier pillars have low safety factor.

The face area develops the low safety factor and may tend to yield. It is found that about 2 to 3 m zone in longwall face subjected to high stress concentration and can yield (Figure 8c).

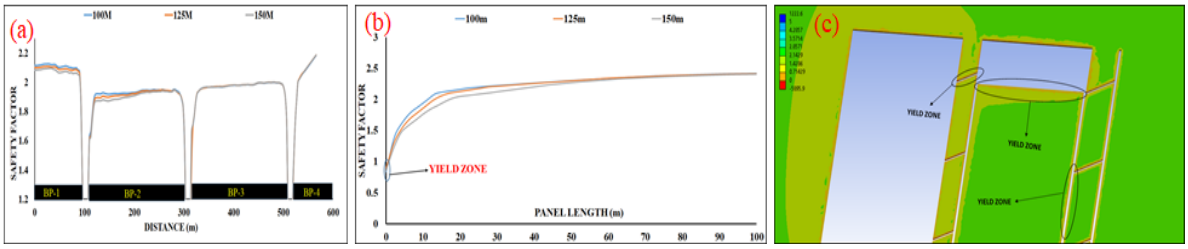

Figure 8. Safety factor distribution of barrier, panel and longwall workings.

5 CONCLUSIONS

A deep longwall panel being operated at 530 m depth is considered to develop 3D longwall finite element models. The variations in pillar size, retreat distance and coal competence are taken for the detailed analysis. It is found that the development of stresses, displacement, abutment and yield zones on the barrier pillars and longwall face increases with increase of retreat distance and reduces with size and coal competency. It is also found that the safety factor on the barrier pillars and longwall face increases with reduction in retreat distance and increase in barrier size and coal competency. The minimum safety factor of 1.82 is found for retreat distance of 150 m and maximum of 1.88 is for 100 m retreat distance on pillar 2. The maximum vertical displacement of 58.46 mm is observed in TG2 and that of 105.20 mm in MG 2 for 150 m retreat distance. It is also observed that about 2 to 3 m yield zone observed at the longwall face.

ACKNOWLEDGEMENTS

This study is supported by a financial grant from the SERB, Department of Science and Technology (SRG/2020/000620). The authors are thankful to the authorities of SCCL for providing the data to carry out the study.

REFERENCES

Colwell, M., Hill, D., & Frith, R. 2003. ALTS II: a longwall gateroad design methodology for Australian collieries. Proceedings of the 1st Australasian Ground Control in Mining Conference, 123–135.

Esterhuizen, G. S., Gearhart, D. F., Klemetti, T., Dougherty, H., & van Dyke, M. 2019. Analysis of gateroad stability at two longwall mines based on field monitoring results and numerical model analysis. International Journal of Mining Science and Technology, 29(1), 35–43.

Gearhart, D., Esterhuizen, G., & Tulu, I. 2017. Changes in stress and displacement caused by longwall panel retreats. Proceedings of the 36th International Conference on Ground Control in Mining, 313–320.

Islavath, S. R., Deb, D., & Kumar, H. 2016. Numerical analysis of a longwall mining cycle and development of a composite longwall index. International Journal of Rock Mechanics and Mining Sciences, 89, 43–54.

Shi, Q., Xu, G., Wang, D., Li, Z., Liu, W., & Wang, X. 2021. Chain pillar optimization at a longwall coal mine based on field monitoring results and numerical model analysis. Arabian Journal of Geosciences, 14(23), 1–8.

Tulu, I. B., Esterhuizen, G. S., Gearhart, D., Klemetti, T. M., Mohamed, K. M., & Su, D. W. H. (2018). Analysis of global and local stress changes in a longwall gateroad. International Journal of Mining Science and Technology, 28(1), 127–135.

Yavuz, H. (2004). An estimation method for cover pressure re-establishment distance and pressure distribution in the goaf of longwall coal mines. International Journal of Rock Mechanics and Mining Sciences, 41(2), 193–205.