Stability of continuous miner workings using numerical modelling approach

Continuous miner technology is one of the mass mining technologies suited for exploitation of deep coal deposits. This method requires less investment and ensures more productivity. This method provides more roof exposure in the form of slices and leaves the small ribs between slices during depillaring operation which may lead to roof fall, side fall and ribs failure. In order to avoid the accidents due to roof, side falls and failure of ribs, the stability analysis of continuous workings is to be performed. In this study, a three dimensional finite analysis is performed for the continuous miner panel. In the continuous miner panel, dip most pillar is depillared and nearby pillar is under splitting condition. The vertical displacements due to this operation are estimated in the working as well as on the surface. The safety factors of ribs are also estimated using Hoek-Brown rock mass failure envelope.

Keywords: *Pillar, roadway, ribs, fender, displacement, principal stress, safety factor*

1. Introduction

There are two popular mining methods; open pit mining and underground mining and are available for winning the coal seams. The openpit mining is suited for shallow deposits whereas underground mining is for winning of deeper seams. The shallow depth coal seams are almost been exploited with open pit mining and getting environmental clearance for opening the deeper open pit mining is a challenging task. For meeting the coal demand of the country, the deeper seams are to be exploited with the underground mining method. The continuous miner and longwall are the two available techniques to exploit the seams of deeper depths. However, the continuous miner technology requires less initial investment than longwall mining. Hence, the continuous miner technology is only an option for exploiting the deeper coal deposits with low budget. This technology extracts more production and ensures high productivity [1-2].

In this method, the continuous miner machine is deployed to cut the coal continuously from the coal face with cutter head of 3.3m width. The cutted coal is gathered with gathering arm provided in the front side of continuous miner. The coal is transported with chain conveyor to rear side of the miner and is loaded into shuttle car of 10 tonnes capacity and this car unloads the coal into feeder breaker [3-4].

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During the depillaring operation, the miner cuts the coal of 15 m length and 3.3 m width in each slice and leaves the rib of 3 m after cutting of two such slices or 6.6 m width in two cuts. This technology provides about 100 square meter area of roof exposure between two ribs and no supports are installed in the slices. This large roof exposure may create the roof fall, side fall, air blast and rib failure. These effects may cause the burial of continuous miner, shuttle cars and other supporting equipment and loss of miners or workmen [4-5]. In order to avoid the ill effects or provide the safe condition, finite element analysis is to be performed to know the stability of the ribs and split pillars.

To complete the above task, three dimensional finite element model is prepared for the continuous miner panel located at 323 m depth. A continuous miner panel consists of 40 pillars of 45 m × 45 m size and gallery width of 4.2 m × 3 m is considered. Out of these pillars, a dip side pillar is extracted in the form of slices leaving the ribs of 3 m width as shown in Fig.4. In the rise side of the depillaring pillar, one more pillar is splitted. The principal stress distributions and vertical displacements are estimated in the continuous miner panel. The safety factors of all the ribs left in the panel are also estimated using Hoek-Brown failure equation.

2. Case study mine

A continuous miner panel of Venkatesh Khani 7, Singareni Collieries Company Limited, Telangana is considered for the study. This mine consists of three workable seams with variable thickness having gradient of 1 in 7.5. The details of the seams with their parting and depths are listed in Table 1 [4-5].

TABLE 1: DETAILS OF THE COAL SEAMS

Seams	Thickness (m)	Gassiness	Parting	Depth (m)	
				Minimum	Maximum
Top	9-11	Degree I	42-52	62	357
King	5.5-10.5	Degree I	42-52	125	425
Bottom	2.6-4	Degree I	5-6	149	298

The top and bottom seams are being extracted with conventional bord and pillar mining method using loadhaul dumper machine. The king seam is adopted with continuous miner technology for the extraction of coal. The continuous miner panel is located at 323m depth and consists of 40 pillars with 45m × 45m pillar size. During the development operation, the panel is developed with 4.2m × 3m roadway considering stone as roof, and then these galleries are being widened to 6.5m and heightened to 4.5m. After commencing the depillaring operation, the dip pillar is splitted into two halfs and each split or half of the pillars are called as fender A (dip side) and fender B (rise side). The fender A and fender B are extracted with slices and keeping the rib between two slices as shown in Fig.4. The left out part of seam of 1.5m is extracted with floor dinting after cutting of slices [1, 2, 4]. In this finite element analysis, the barrier pillars are considered as intact with the coal seams. Hence, a total of 18 pillars are seen in the numerical model (Figs.3 and 4). The three dimensional finite element model is developed based on the lithology given in the Fig.1. The strata lying above and below the coal seams are sandstone rock and the top seam of 9.5m thick is also existed at 271m depth as shown in Fig.2.

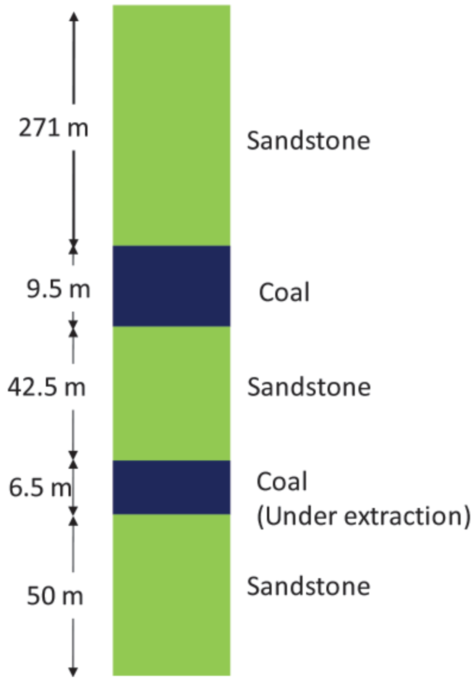


Fig.1 Lithology of mine site used for finite element model

3. Numerical model of the continuous miner panel

A total of two (2), three dimensional finite element models are developed based on the lithology of mine site (Fig.1). They are in situ model consists of virgin coal seam and other coal bearing strata and excavation model consists of depillared pillar, developed pillar, roadways and surrounding rock mass. All the finite element models have been analyzed based on elastic behaviour of the rock mass [6-7].

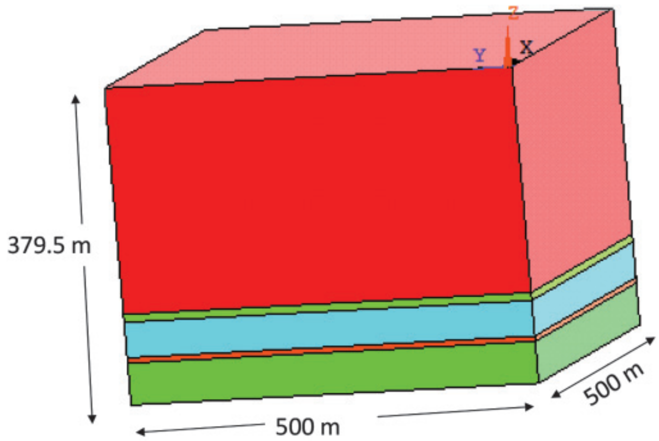


Fig.2 Continuous miner panel

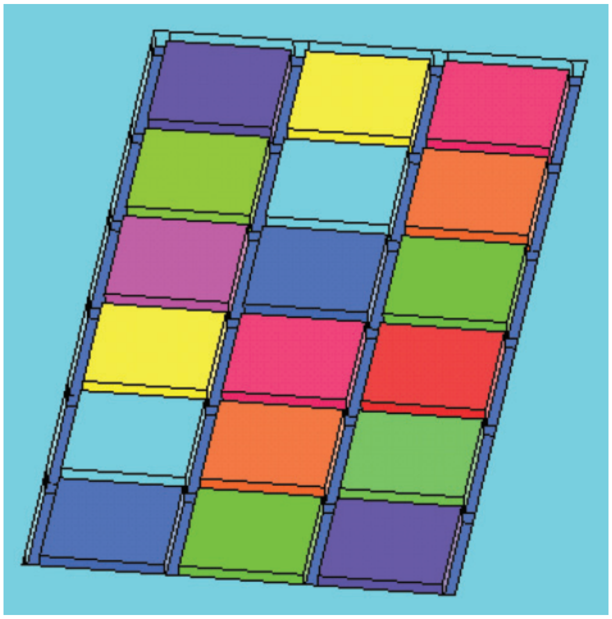


Fig.3 Development of the coal seam forming the pillars and galleries

3.1 Continuous Miner Panel

The virgin coal seam is developed with eighteen pillars consists of seven level galleries and four dip galleries. The size of the model or continuous miner panel is 500m × 500m × 379.5m. Fig.3 shows the king seam is developed with eighteen pillars with 45m × 45m pillar size and gallery of 4.2m × 3m. The size of pillars and roadways are made of 45m × 45m and 6.5m × 6.5m after extraction. The dip side pillar is extracted in the form of slices and ribs. The slices are extracted with 600 angle from horizontal (Fig.4c) and the pillar adjacent to the depillared pillar is splitted into two halves (Fig.4b). Fig.4 shows the pillar having ribs and slices [6-7].

3.2 Rock Mass Properties

The rock mass properties of coal bearing strata of mine site are collected and used as input for the finite element analysis. Rock mass properties such as stiffness (*E*), density

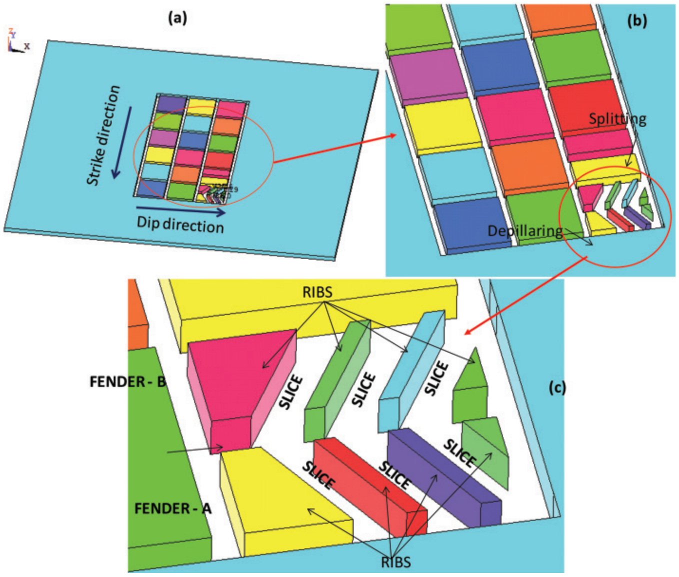


Fig.4 Extraction of the coal seam with continuous miner

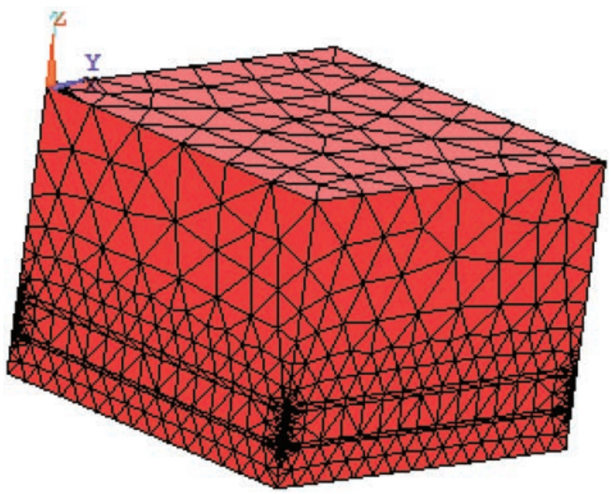


Fig.5 Finite element mesh model of CM panel

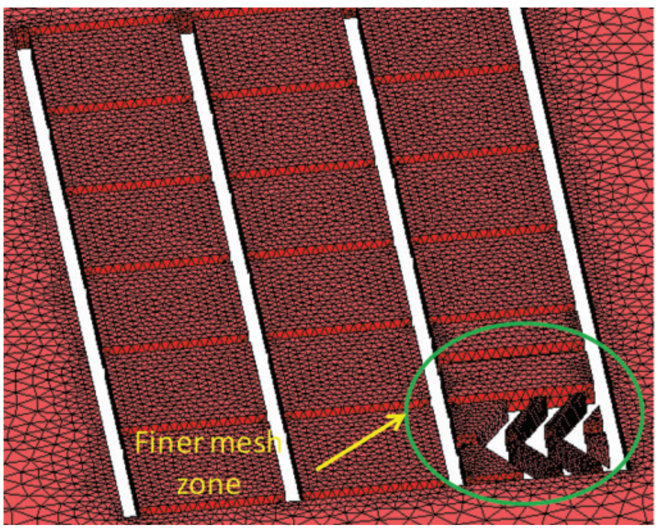


Fig.6 Finite element of coal seam

(ρ), poison's ratio (υ) and rock mass rating (RMR) are listed in Table 2. Table 3 lists the compressive strength of intact rock and the Hoek-Brown rock mass parameters [8-9].

3.3. Generation of mesh of continuous miner panel

The continuous miner model produces an average of 232770 8 – noded tetrahedron elements and 44059 nodes and the coal seam produces 102324 8 – noded tetrahedron elements and 26962 nodes. Figs.5 and 6 show the meshed model of entire continuous miner panel and depillared coal seam respectively. The finer size elements are developed near to the depillared area where the displacement and stress are to be determined [6-7].

The size of the model is 500m × 500m × 379.5m are applied the horizontal pressure of 1.5 times of vertical pressure in both strike and dip directions. The gravitational force is applied along the vertical or z-axis direction.

4. Results and discussions

The results in terms of vertical displacement in the roof of the coal seam and at the surface are discussed. The principal stress distributions around the ribs and slices of the depillared pillar are also presented. The safety factors of the ribs left out during the depillaring operation are estimated based on the Hoek-Brown rock mass failure criterion [7,8,10].

4.1 Displacement distributions

Fig.8 shows the vertical displacements profile in the roof of the coal seam are obtained along the various paths considered as shown in Fig.7. Paths 1 and 2 are taken along the ribs and slices near to the splitted and barrier pillars respectively. However, the path 3 is considered along the split gallery of the depillared pillar. The maximum vertical displacements are observed along the paths 1 and 2 are 121 mm and 119 mm respectively. A vertical displacement of 2mm more is occurred in the path 2 due to splitting of pillar near to the path. The vertical displacement of 124mm is occurred along the path 3 as it is considered along the split gallery (Fig.8).

In the continuous miner panel, a maximum of 327mm is occurred at the surface of the panel and it is observed that

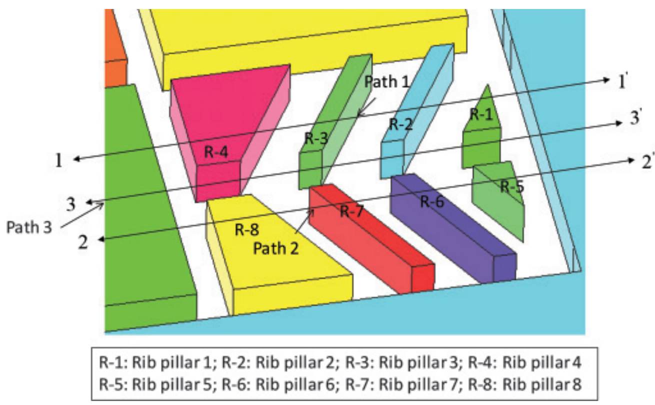


Fig.7 Various paths considered for the detailed analysis

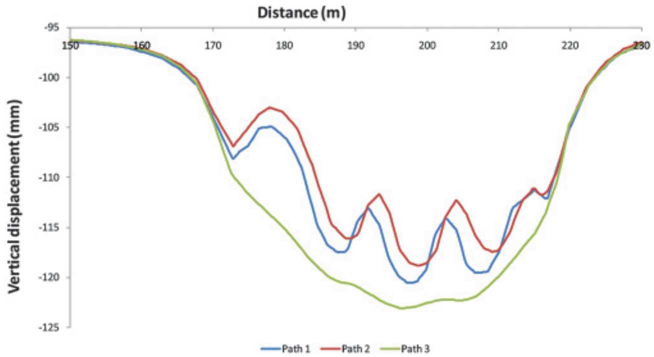


Fig.8. Vertical displacement distribution around various paths

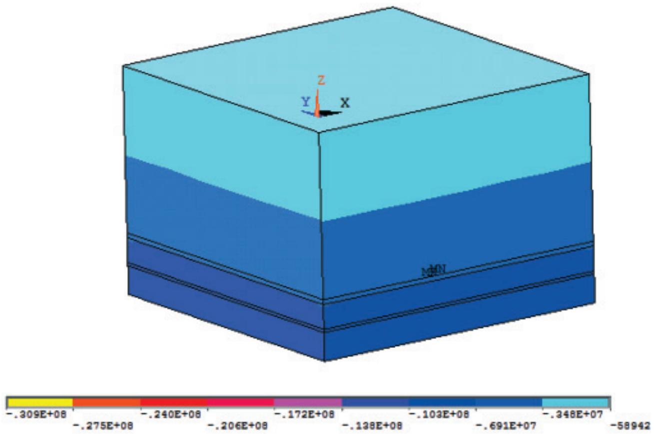
the value of vertical displacement reduces with depth and the displacement occurs in the coal seam between 108mm to 145mm.

4.2 Principal Stresses Distribution

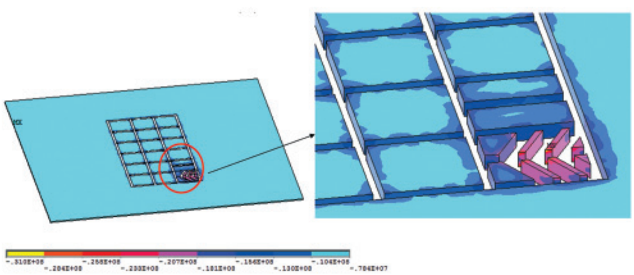
The major principal stress distribution in the continuous miner panel varies between 0.058 MPa to 30 MPa and the coal ribs are experienced with 20.7~31 MPa as shown in Fig.9. It is also found that the major principal stress occurs in the split pillars near to the depillaring operation between 13 and 15.6 MPa. The effect of major principal stress decreases in the pillars away from the depillaring pillar.

(a) Entire model

(b) Continuous miner panel



(a) Entire model



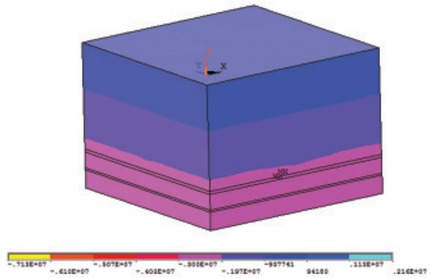
(b) Continuous miner panel

Fig.9 Major principal stress distribution

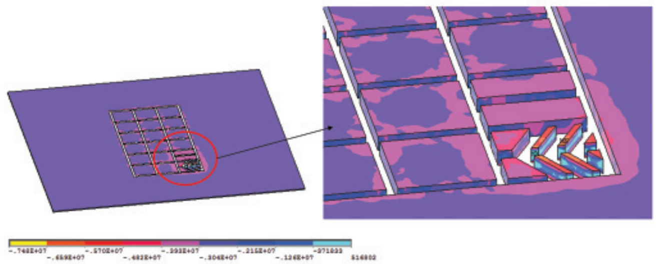
The minor principal stress distribution in the continuous miner panel varies between 2MPa (tensile) to 7.12MPa (compression) and the coal ribs are experienced with 3.9~7 MPa as shown in Fig.10. It is also found that the major principal stress occurs in the split pillars near to the depillaring operation between 2.15 and 3.93MPa. The effect of minor principal stress diminishes with the increase of distance from the depillaring pillar.

(a) Entire model

(b) Continuous miner panel



(a) Entire model



(b) Continuous miner panel

Fig.10. Minor principal stress distribution

Table 2: Rock mass properties used for finite element analysis

Rock type	Stiffness, E (GPa)	Poisson's ratio, υ	Density, ρ (Kg/m^3)	RMR
Coal	1.25	0.35	1300	50
Sand stone	5.5	0.25	2400	65

Table 3: Compressive strength and Hoek and Brown rock mass properties

Rock type	m_i	m_b	s	a	σ_{ci}(MPa)
Coal	10	5.443591	0.003866	0.505734	28
Sand stone	19	1.676772	0.020468	0.501975	35

4.3 Factor of Safety

The safety factors have been calculated along the roof of ribs left out in the depillaring operation and split gallery using Hoek-Brown rock mass failure criterion. For each rib, ten critical points are considered on top of the ribs along the paths 4, 5, 6, 7, 8, 9, 10 and 11 for estimation of safety factors (Fig.11). Figs.12 and 13 show the distribution of safety factor along the paths from 4 to 11 of the ribs. The safety factor of rib pillars and split gallery are also estimated along the paths

TABLE 4: SAFETY FACTOR OF THE RIBS AND SLICES (ALONG THE PATH 1)

Locations	(Pa)	(Pa)	Safety factor
1	-2738400	-11551000	0.24
2	-2695200	-12876000	0.21
3	-453590	-6504500	0.071
4	-1550900	-9834100	0.16
5	1173400	-3950700	Tensile failure
6	1247300	-6035200	Tensile failure
7	-704330	-9898600	0.072
8	1707800	-2385900	Tensile failure
9	-2067400	-10790000	0.19
10	-2035800	-10687000	0.19

TABLE 5: SAFETY FACTOR OF THE RIBS AND SLICES (ALONG THE PATH 2)

Locations	(Pa)	(Pa)	Safety factor
1	-2948000	-11435000	0.26
2	-3020800	-12188000	0.25
3	-2218500	-11132000	0.20
4	154460	-3302400	Tensile failure
5	-1577800	-10788000	0.15
6	712430	-1571900	Tensile failure
7	-2793900	-13838000	0.20
8	264430	-1516800	Tensile failure
9	-1304200	-9272400	0.14
10	-1856800	-10859000	0.17

TABLE 6: SAFETY FACTOR IN THE ROOF OF THE SPLIT GALLERY (ALONG THE PATH 3)

Locations	σ_3(Pa)	σ_1(Pa)	Safety factor
1	-1279200	-2573300	0.50
2	-430800	-1953600	0.22
3	726130	-697740	Tensile failure
4	886370	-595580	Tensile failure
5	1178300	-134060	Tensile failure
6	875890	-514430	Tensile failure
7	1037600	-341980	Tensile failure
8	781200	-653340	Tensile failure
9	114380	-1538900	Tensile failure
10	106100	-1395600	Tensile failure

1, 2 and 3 and listed in Tables 4, 5 and 6.

The factor of safety is an indicator to show the extent of safety associated with a pillar. The factor of safety (SF) is defined as the ratio of the strength (R) of the pillar over stress (S) acting on pillar [7, 8, 10]. It is expressed as:

$$SF = R/S \qquad \text{... (1)}$$

A pillar is considered to be stable if safety factor is greater than 1.0. From the Hoek-Brown yield criterion.

$$SF = \frac{\left(\sigma_3 + \sigma_{ci}\left(m_b \frac{\sigma_3}{\sigma_{ci}} + s\right)^a\right)}{\sigma_1} \qquad \text{... (2)}$$

where,

$$m_b = m_i \exp\left(\frac{GSI-100}{28}\right), \quad s = \exp\left(\frac{GSI-100}{9}\right),$$

$$a = \frac{1}{2} + \frac{1}{6}\left[\exp\left(^{-GSI}/_{15}\right) - \exp\left(^{-20}/_{3}\right)\right]$$

ω_{ci} and m_b, s, a are uni axial compressive strength and Hoek-Brown rock mass parameters.

Table 3 lists the safety factor of the ribs and slices along the path 1, it may be noticed that the safety factor varies from 0.19 to 0.24 and the maximum value of 0.24 lies in the rib pillar 4. The slices between rib pillar 3 and 1 are experienced with tensile stress and yields due to the high tensile stress concentration (critical locations at 5, 6 and 8).

From the Table 4 or along the path 3, the safety factor values are slightly improved than path 1 as the ribs and slices nearer to barrier pillar. A maximum safety factor value of 0.24 occurs in the rib pillar 8 and other part of the ribs and slices are under tension and yields due to tensile stress.

It may be noted that the safety factor of the split gallery (path 3) lies 0.22 to 0.5 (critical points 1 and 2) near to the undeveloped pillar and other part of the split gallery is under high tensile load. Hence, critical points from 3 to 10 are yielding due to tensile load. Table 5 lists the safety factor of the split gallery or along the path 3.

Figs.12 and 13 show the safety factor of the ribs left out in the fender A and B. From these figures, it is noticed that all the critical points of both the fender A and B yields due to high compressive load. The maximum safety factor value is reported to be 0.22 at rib pillar 4 of fender A whereas 0.24 at rib pillar 8 of fender B because of both rib pillar 4 and 8 have the larger area. The other rib pillars of 3 m in width are left in the depillaring operation; hence these pillars are reported to be lower value.

It is found that the safety factor lies less than one and yield due to high tensile and compressive load in all the paths

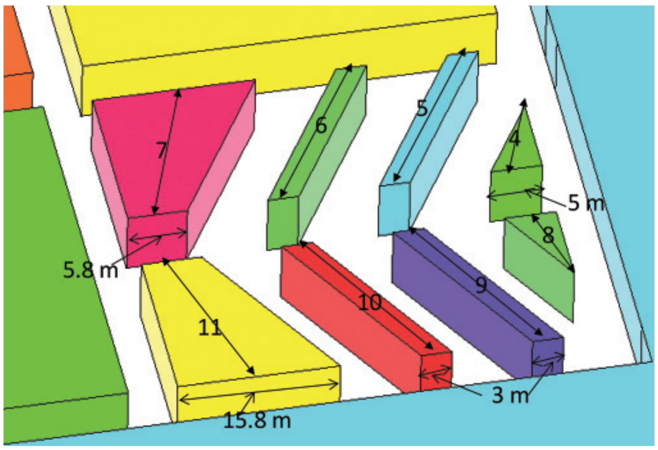


Fig.11 Various paths considered for estimation of safety factor

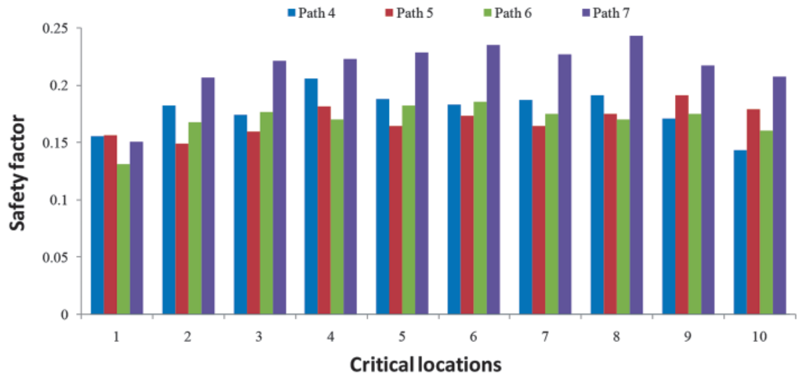


Fig.12 Safety factor of Fender B

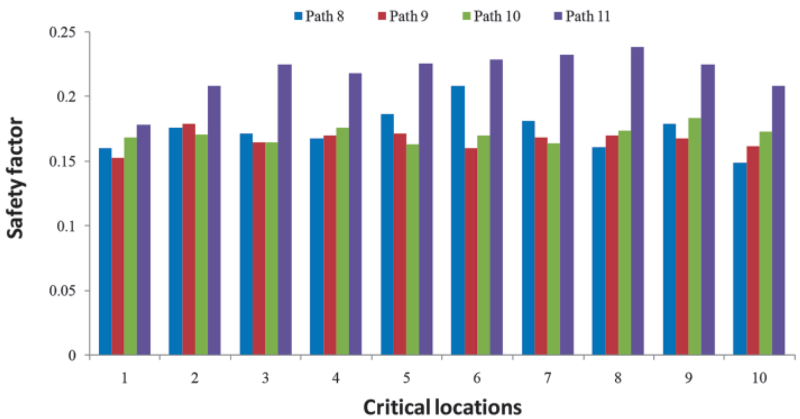


Fig.13 Safety factor of Fender A

considered for the detailed analysis. Hence, proper supporting system is adopted for safe extraction of coal using this continuous miner technology.

Conclusions

From the three dimensional numerical analysis, a maximum vertical displacement may go up to 124 mm along the path 3. However, the displacement occurred along the paths 1 and 2 is 121 and 119 mm. A vertical displacement of 2 mm more is occurred in the path 1 due to the splitting of the pillar.

The maximum compressive major principal stress of 30 MPa may occur in depillaring panel. The rib pillars experience the compressive major principal stress with a range between 20.7 and 31 MPa. The split pillar experiences the major principal stress between 13 and 15.6 MPa.

The minor principal stress distribution in the panel varies between 2 MPa (tensile) to 7.12 MPa (compression) and the coal ribs are experienced with 3.9~7. The split gallery of depillared pillar is experienced under high tension. The effect of the major and minor principal stresses diminishes in the virgin pillars.

The maximum safety factor is found to be 0.5 in the split gallery or along the path 3 near to the undeveloped pillar and the entire gallery is yielded due to high tensile load. From the paths 1 and 2, a safety factor value of 0.24 and 0.26 are reported in the rib pillar 4 and 8. It may be noted that the safety factor of 0.22 and 0.24 lies near to the virgin pillar along paths 7 and 11. The value reduces towards rib pillar 1 and rib pillar 5 of fender A and fender B respectively.

From the above study, the entire continuous miner depillaring pillar is experienced with high stress concentrations and yields due to compressive and tensile load. Hence, proper supporting system is to be selected and adopted to achieve high production and productivity with safety.

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