SHYAM SUNDAR PRASAD
RABINDRA KUMAR SINHA
and
BODIGA RAMBABU

Numerical modelling approach for assessment of factor of safety of ribs in continuous miner depillaring panels – a case study of Churcha mine

Continuous miner (CM) technology is being adopted as a successful mass production technology for working coal seams by underground (UG) method in India. This technology is getting established as an ideal option to meet the objectives of the high output, productivity, and safety with a moderate level of investment. In UG coal mines, the success of the bord and pillar method of working largely depends on the depillaring operations, as the maximum coal recovery is achieved during these operations. CM panels in India, especially during depillaring operations, experience in numerous problems like premature collapses, overhanging roof, partial extraction in a panel, etc., as some of the significant parameters influencing the stability of UG structures are still not standardised. As such, there is an urgent need to have a better understanding of the behaviour of UG structures, overlying roof and sidewalls for efficient and effective designing of the depillaring operations with particular reference to geo-mining conditions. This paper deals with a brief review of the strata control problems faced in CM workings and study of stress distribution for assessing the optimum factor of safety (FOS) of the ribs in CM depillaring panels by using numerical modelling as a tool. This model can be applied for assessing the pattern in variation of FOS of the ribs in CM depillaring panels for safe extraction of coal or, alternatively, for designing the ribs in such panels by fixing the threshold limit of the FOS of ribs for a particular geo-mining condition.

Keywords: Numerical modelling, FOS, geo-mining, threshold limit, augment, fenders.

1.0 Introduction

Coal production in India is predominantly from surface mining, which accounts for about 94.5% of the country's total coal output. In contrast, only 5.5% of it is contributed by UG mining (Annual Report, 2019-20, official website, Ministry of Coal, Govt. of India). However, in the backdrop of increasing coal demand and fast depleting shallow reserves, in the future, there is no option but to augment the UG coal output by adopting mass production technology. Having experienced the limited success of LW and blasting gallery method in Indian mines and looking at global trends, CM-based technology may be ideal for high production, productivity, and safety for Indian geo-mining conditions (Das, Mandal, Paul, Sinha and Tiwari, 2018).

In Indian conditions, many coal seams extensively developed in the past have left prime coal locked up as standing pillars under varying geo-mining conditions at depth usually from 50 to 500m (Rajendra Singh, Mandal, et al., 2011). Such standing pillars also pose the problem of not enabling the extraction of the lower seams below (Kumar et al., 2018). Conventional depillaring of such workings not only results in low production and productivity but also poses challenging ground control issues and thus has limited technical and economic viability. Working culture in Indian UG coal mines is most adapted and conversant with the bord and pillar system of working, and CM is such a technology that can be deployed for both development and depillaring operations in the bord and pillar system. In India, especially to extract the standing pillars, this technology has been deployed for mass exploitation of coal (Agrawal., 2015).

The CM technology was first introduced in India by South Eastern Coalfields Limited (SECL) in 2002 at Anjan Hill mine when the roof bolt based breaker line support system was successfully implemented for the first time in the country. The above result encouraged deploying the CM technology in a few other mines (Mandal et al., 2004). Since then the technology is further implemented in many mines under varying geo-mining conditions, such as, the NCPH, Churcha (RO), Sheetaldhara, Khairaha, Haldibari, Vijay West, Pinoura, Bangwar, and Rani Atari mines of SECL, Jhanjra, Sarpi, Khottadih and Kumardih-B mines of ECL, Churi UG project of CCL, Tandsi and Tawa-II mines of WCL and GDK-11 incline, VK-7 Incline, Shanti Khani Incline and Padmavati Khani (PVK shaft) mines of SCCL, of which in many cases depillaring operation has been practiced. Extraction techniques, like split and fender method, Nevid method, fish

Blind peer reviews carried out

Messrs. Shyam Sundar Prasad and Rabindra Kumar Sinha, Department of Mining Engineering, Indian Institute of Technology (Indian School of Mines) Dhanbad, Jharkhand 826004 and Bodiga Rambabu, KLR College of Engineering and Technology (Affiliated to JNTUH) India. E-mail: rksinha@iitism.ac.in

and tail method, double split and fender method, one-third split and fender method, etc. have been practiced successfully in Indian conditions. The CM technology can get a recovery of 60-74% depending on the geo-mining conditions compared to 50-60% in the case of the semi-mechanised panel with SDL or LHD operation (Mishra et al., 2013). With this encouraging history of about 19 years in the Indian mines mentioned above, large-scale adoption of CM technology in the future may prove to be a breakthrough to extract such valuable coal reserves profitably and safely.

Globally, the CM technology has not only proved to be a successful method of mining in room and pillar system achieving high production, productivity, and safety but has also become a preferable option for it is less capital intensive and offers better flexibility compared to the LW system in geologically disturbed and irregular coal seams. From stability perspective, Australia and the US have faced the problems of rib failures, delayed caving, and fall of gallery intersections and surpassed the problems by proper geotechnical assessment maintaining previous mines database and deploying the mobile breaker line support system (R. Singh et al., 2011). In European collieries, pillar extraction methods are not widely practiced due to the existence of the deeper coal seams (depth>300 m) when compared to coal deposits in Australia and South Africa (Lind, 2002). At greater depth, usually, LW technology is practiced because of the high-stress condition but in a financial point of view, the ratio of cost of the equipment to the cost of manpower is high which makes them shift towards adoption of another mass production technology called CM technology (Lind, 2002) (Christopher mark, 1997). Since 1958, South Africa has been experienced in deploying CM of different types for retreat mining operations in the Coalbrook, Sigma, Usutu, South Witbank collieries, Tavastik collieries, Phoenix collieries. Cleat-free, harder, and more abrasive rock conditions in the mines accounted for the varying degree of application of machines (J.D.Inch et al., 2011). Australia, also, has huge experience in executing the CM technology over 50 years in the various parts of New South Wales and Queensland. They also designed pillar extraction techniques like Wongawilli method, Old Ben method, Munmorah method, or modified Old Ben which are highly successful in their geo-mining conditions (Lind, 2002).

In the US pillar recovery accounts for more than 75% of room and pillar mining of Appalachian coalfields (Christopher Mark, 2017). CM technology has been deployed widely in seven states, i.e., Southwest Virginia of Virginia, Kentucky, Colorado, Pennsylvania, Tennessee, Utah, West Virginia for retreat mining practices. Various pillar extraction techniques like left-right method (Christmas tree cutting sequence), outside lift, split and fender, pocket and wing, Old Ben, modified Old Ben, combination of Christmas tree, and outside lift methods have been practiced in the above-mentioned states. US has deployed the CM technology in many mines of Southern Appalachian coalfields in pillar recovery operations for increasing the production but unfortunately, it resulted in fatalities between 1989 and 1996 (Chase, McComas, Mark and Goble, 1997).

2.0 Strata control problems in CM panels

In New South Wales mines of Australia, massive strata span over 60-70m before major fall has taken place resulting in crushing of ribs and sudden fall of large span causing air blasts (Lind, 2002). In the US, since 1978 during retreat mining operations 21% of rib/roof fall have been reported and during retreat mining operations at greater depth, 40% of the fatalities are reported. Since 1994, 24 fatalities have been reported due to rib falls (C.Mark et al., 1997). Most US mines face problems like pillar squeeze i.e failures are non-violent usually take hours, days to develop, pillar collapses due to slenderness of it, and bumps at greater depth. During retreat mining, in 2004, one disaster in Alabama took 13 lives and in 2004, 8 miners were killed due to massive roof falls, i.e. falls that extend above the horizon of the roof. In 1992, when the splitting operation was going on in Southern West Virginia, fenders in a 2.3 hectare area collapsed suddenly and causes air blast resulting in fatalities (C.Mark et al., 1997).

While practicing depillaring operations in Indian mining conditions, the nature of the overlying strata encountered varies from easily cavable of Pinoura mine to massive and strong roof of VK-7. Tandsi mine of WCL, has experienced unstable and difficult roof conditions which although partly addressed with proper roof bolting systems, but allowing only the partial extraction (Mukhopadhyay and Sharma, 2017; Ram et al., 2015). VK-7 mine being one of the deepest mines with CM technology poses strata problems due to massive roof and in the Jhanjra mine caving is delaying due to high cavability index in which caving was initiated by blasting from the surface (Ram et al., 2015). Similarly, in Churcha mine (RO) of SECL, the high cavability index and high RQD (>80%) of overlying roofs put the roof strata in the category of "cavable with substantial difficulty", needing induced blasting with long holes for regular caving.

For introducing CM technology on a large scale, few essential tasks should be exercised. Rockmass behaviour and classification of ground conditions have to be known by the field and laboratory investigations for application of CM technology, and design of methodology has to be worked out for extracting the standing pillars at a specific site. Then, an exercise for selection, design, and development of a suitable machine for extraction, evacuation of coal and support of roof strata should be completed before going for the field trials. During the field trial, one has to carefully evaluate the field performance and improvement scope in the system (Mandal, Kumar and Sinha, 2006).

3.0 Significance of snook design in CM panel

Snooks are remnants after the pillar extraction process which

act as temporary support and enable safe working while practicing depillaring. If the full extraction is practiced, there is always a contradiction that, on one hand, caving should happen to minimise the loads on the active pillar line but on the other hand, the caving must not occur until the workers move to a safe position. Failure occurs towards the goaf side when the snook has the ability to withstand the load and act as a breaker line and if the snook is incapable to withstand roof load then both snook and roof will fail. So snook plays an important role in deciding the position of the crack (Vervoort and Jack, 1992). Gallery intersections become unstable if the snook was removed or the size was decreased to too small as it failed to support (Christopher Mark and Zelanko, 2001). The size of the snook should be optimised so that it prevents roof failure and enable the CM to pass through gallery intersections and also increases the percentage of extraction (Ghasemi et al., 2012). So a well-designed nook becomes a key element in maintaining the stability of the workings.

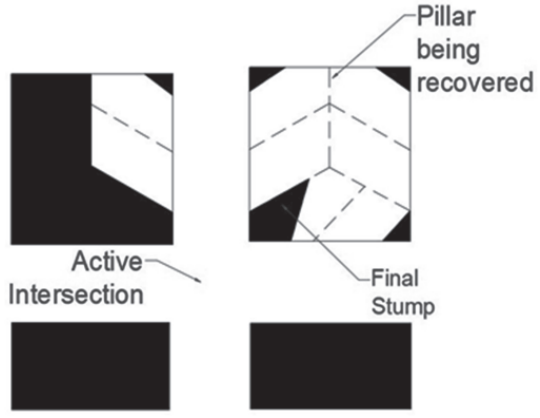


Fig.1 Typical retreat mining geometry (after C.Mark and Zelanko, 2001)

4.0 Stability assessment of ribs

In this study, stability has been estimated by finding out the factor of safety (FOS), i.e. ratio of the strength to the stress acting on the various elements of the CM panel i.e. ribs, fenders, barriers, roof, and solid pillars. These natural structures rib/fender/solid pillar play a prominent role in understanding the strata behaviour and their management (S. K. Singh et al., 2017).

It is desirable to design ribs/fenders in such a manner that they remain stable until depillaring operation at the specific location continues and fail after the depillaring at that location is completed so as to avoid the overhanging of the roof. Rock mechanics designers face challenges for ensuring the optimal stability of the ribs/fenders due to uncertainties and unique strata conditions during depillaring operations in India (S. K. Singh et al., 2017).

4.1 Parameters Influencing Induced Stress on Ribs

Generally, the hosts of influencing parameters for the development of induced stress for flat seam include depth of working, characteristics of overlying strata, width and height of extraction, distance from the face line and treatment of goaf (A.K. Singh, Singh, Maiti, Kumar and Mandal, 2011).

When the workings are at greater depth, pillars will be subjected to greater stress so the size of pillars should be enough to sustain that high-stress environment. The characteristics of the overlying strata also have significant impacts on the development induced stress. In depillaring operation with strong massive overlying strata condition, the overhang of the roof due to delayed caving results in induced stress in the pillars and dynamic loading of the supports during breaking or fall. Hence, assessment of the mining-induced stress due to the overhanging roof for maintaining the stability of the depillaring workings, i.e. optimising the natural and artificial support, is of paramount importance. The distance from the face line does have effects on the induced stress. The pillar near the goaf line is subjected to greater stress than the pillar away from it for which the majority of roof fall accidents in the mine take place in an active mining zone near the goaf line.

The height and width of extraction are other important factors that influence induced stress. If the height of extraction is more, then the area of exposure will more inducing more stress on the pillars. Similarly, narrow width of extraction induces less stress on strata compared to the greater width of extraction. We have experienced greater width of extraction especially in CM panels for easy maneuvering of CMs. The induced stress also depends on how the goaf is treated. If the pillar extraction is done with caving, then the roof should cave regularly otherwise more stress will be induced in the pillars near the goaf line. So in such cases, either stowing should be practiced or induced blasting should be done.

4.2 Estimation of Induced Stress over Ribs

The estimation of stress which is developed in UG structures during depillaring operations may be done by empirical methods, field investigations and numerical modelling.

The empirical method is a tributary area method used for the estimation of load in symmetrical pillars only, i.e. the pillars formed during development. However, during depillaring operations, mostly the irregular-shaped ribs/fenders are formed, so the tributary area method cannot be applied in this case. Empirical formulations developed by the researchers are mostly site-specific, i.e. based on the geo-mining conditions and limited to range-specific of considered parameters. For example, the estimation of average induced stress can be calculated around symmetrical excavation by tributary area method but it has the limitation of roof strata failure and high recovery percentage (Satyanarayana and Budi, 2015). It is given by

$$\text{Average induced pillar stress } \frac{\gamma \times H}{1-R} \quad \ldots (1)$$

where, γ = weight per unit volume

H = depth of the working (m)

R = Percentage of extraction

Based upon the linear Load Transfer Distance concept (LTD), the average pillar stress in the zone of influence (ZI) established by Poulsen, if the excavation is made in pillar zone of influence, is given by (A. K. Singh et al., 2011)

$$\text{Average induced stress} = \frac{\rho \times g \times H \times \pi\left(2LTD + \frac{We}{2}\right)^2}{\pi\left(2LTD + \frac{We}{2}\right)^2 - a_e} \quad \ldots (2)$$

Where, αe = excavation area (m)

H = depth of the cover (m)

w_e = Effective width (m)

$LTD = 1 \times 10^{-4} H^2 + 0.2701H$ (m)

Under field investigation method, an instrument like a vibrating wire type stress meter is mostly used for estimating the vertical stress and for measuring in-situ stress, a flat jack is used. Especially in depillaring operations, working conditions are not good enough to carry out such field investigations, and installing the instruments in the pillars will be extra cost too.

Numerical modelling is the best tool for overcoming the problems that arise by using empirical methods and field investigations, i.e. site-specific instrument's cost, hazardous working conditions, etc. It is the best for evaluating geotechnical assessment of the mine structures under varying stress conditions prevailing at the mine site and it provides the platform to conduct a parametric study to find the geotechnical design of mine structures.

5.0 Case study of Churcha mine

Churcha Mine (RO) consists of two adjacent blocks, i.e.



Fig.2: Google map view of Churcha mine

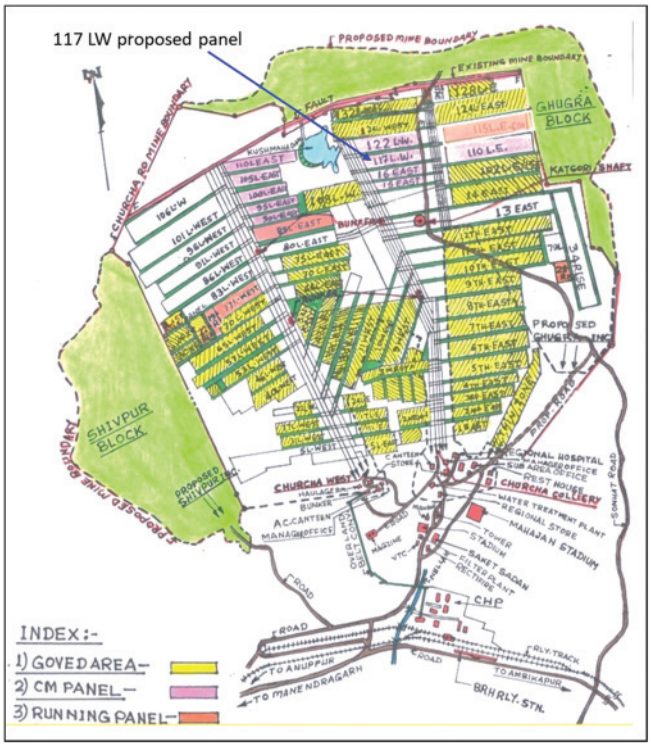


Fig.3: Plan of Churcha colliery

Churcha East and Churcha West blocks of Baikunthpur Area of SECL, in Korea district of Chattisgarh state. Location of Churcha mine is given in Fig.2. As per Project Report, the mine is planned for coal production of 1.84 million tonnes per year with the deployment of 2 CM packages, 5 numbers 3 m^3 LHD, and 6 numbers 1.5 m^3 LHD (Churcha Safety Report, 2016).

Churcha mine is located in Sonhat coalfields which is a part of the Rewa Gondwana basin. There are 7 seams occurring within the property, of which Seam V is the only workable seam of thickness ranging from 3 to 4m. The coal-bearing formations exhibit north-east to south-west strike with a gentle northerly dip of 5º to 10º. The surface topography of the mine block is hilly terrain, which makes it difficult to extract coal by conventional mining method as the load acting on the pillars is more and the rate of extraction was also less. An important geological feature of the deposit is the presence of a 75 to 163m thick dolerite sill occurring between 38 to 190m above the seam. Except for a small patch on the rise side, almost the whole mine is covered by the sill. The depth of cover of the seam varies from 300 to 420m. A small layer of shale having a thickness of 0.1 to 1m is present in the immediate roof, which gets separated from the roof on exposure, and above that layer, a massive competent sandstone roof exists up to dolerite sill. The southern boundary of the area is demarcated by the east-west trending major fault F1-F1 hading southwards. Its throw is likely is to more than 150m. Fault no. F3-F3 having ENE-WSW trend shows southerly throw. Towards the eastern part, its throw is

12m which gradually decreases westward to 5m.

117 Level west panel of the mine, proposed for depillaring by deploying CM technology, was selected for the case study, the location of which is shown in Fig.3. The panel was at around 300m depth, with pillar size 44m×39m with gallery width 6m.

The double split and fender system of working was proposed considering optimum utilisation of the CM and safety. The fender length should match with the cut-out distance of the CM for optimum utilisation.

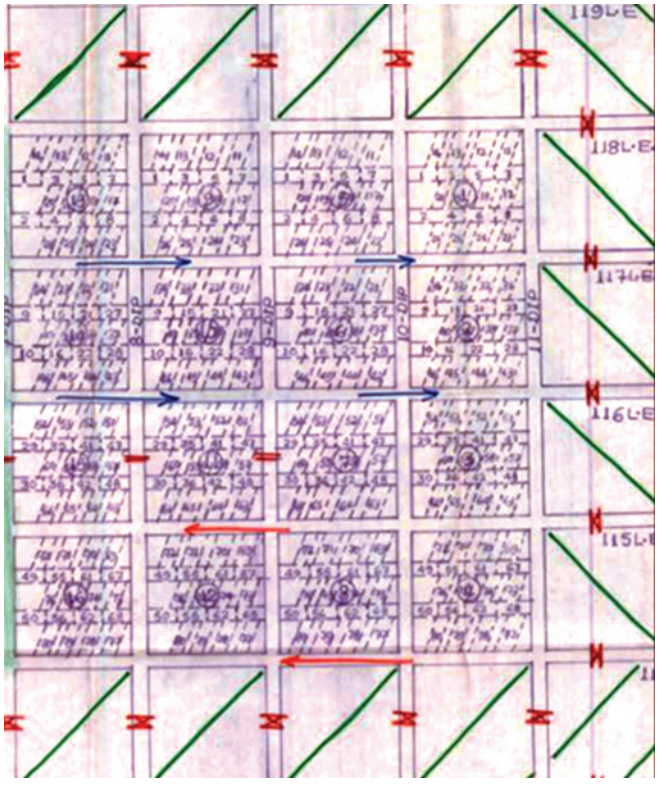


Fig.4(a) : Churcha mine 117 LW panel - area considered under analysis

6.0 Numerical modelling of depillaring panel

Numerical methods are used to simulate the physical models in rock engineering by defining the geometry of the model, constituents and its behaviour, geological structures, etc. to solve the problems in the geotechnical field. It will be hazardous, risky, time, and money consuming for doing the parametric study in the field and so in that case, numerical methods are very useful to do parametric study under these varying geo-mining conditions. The most popular computational numerical methods are finite element method, boundary element method, discrete element method and finite difference method.

ITASCA FLAC^{3D} - Fast LaGrangian analysis of Continua is the oldest and powerful finite difference programme to solve partial differential equations in engineering mechanics. The

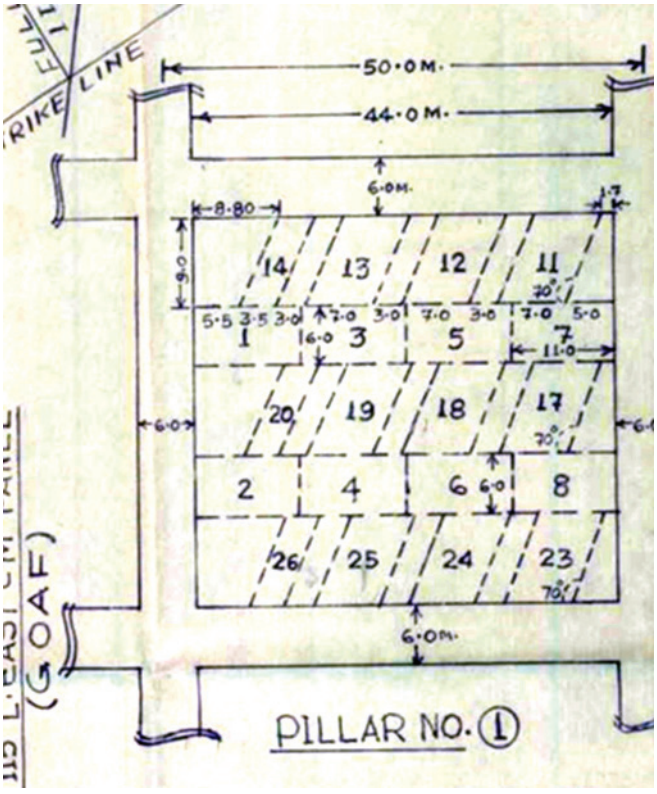


Fig.4(b): Double split and fender - Churcha mine

main concept of this method is solving field variables i.e. stress, displacement, etc. at grid points and nodes in the form of algebraic simultaneous equations are approximated by the differential equations and those equations are solved by applying appropriate boundary conditions to estimate the values of the field variables at grid points of the discretised domain. Nowadays, the use of FLAC^{3D} increasing in large numbers to solve the geo-mechanics problem due to the adaptability of the mixed zoning method and LaGrangian scheme to ensure the plastic flow and collapse are modelled satisfactorily to solve the problems accurately. (FLAC^{3D} manual)

The extension of the FLAC^{3D} usefulness increased by a special programming language called FISH which allows the users to define new functions and variables and this language is embedded in the FLAC3D software. (FLAC^{3D} Manual)

6.1 Meshing and Model Generation

Based on the geometry obtained from the data collection, grid generation has been done. Tables 1 and 2 show the panel modelling parameters and properties of coal, roof, floor, and immediate roof respectively.

6.2 FLAC^{3D} Modelling

Discretised Model of 117 LW panel of Churcha mine has been developed, which is illustrated in Fig.5.

For applying loading conditions on the above model,

Table 1: Panel modelling parameters

Depth of working	300 m
Barrier width	100 m
Immediate roof (medium grain sandstone)	1 m
Floor depth	50 m
Height of the working	3 m
Panel geometry	Modelled as shown in Fig.4(a)

Material model: Model mechanical Mohr-Coulomb

Table 2: Properties of coal, roof, floor, and immediate roof

Rock parameters	Coal	Roof	Floor	Immediate roof
Bulk modulus (GPa)	2	3.2	3.8	3.5
Shear modulus (GPa)	1.2	1.92	2.28	2.1
Density (kg/m^3)	1400	2300	2300	2210
Cohesion (MPa)	0.78	2.17	2.17	1.38
Tensile strength (MPa)	2.10	3.72	3.72	3.5
Friction angle	36.50	37.44	37.44	34.88

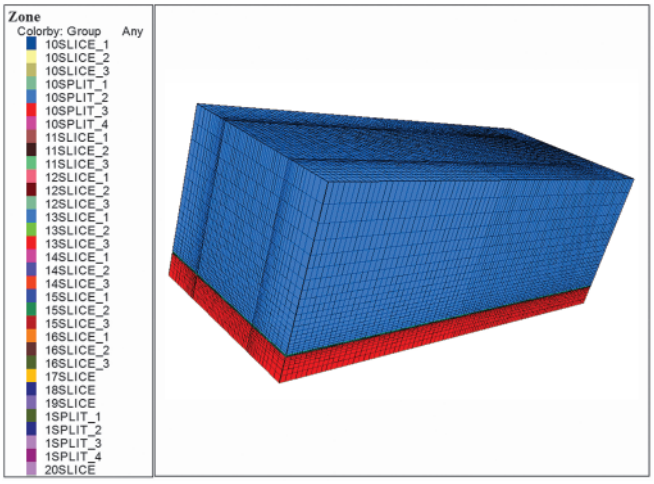
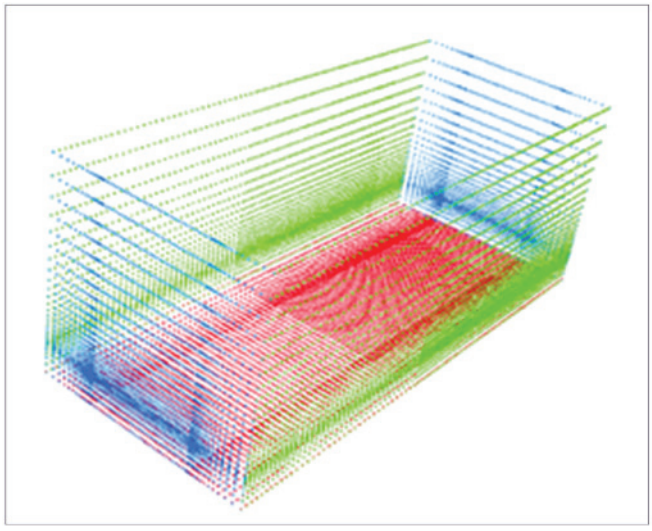


Fig.5 Discretised model - Churcha panel


Fig.6 Applied boundary conditions

initial conditions, boundary conditions must be applied and gravitationally loaded, the illustration of which is shown in Fig.6.

For knowing whether the model reaches a steady state or not it can be known by plotting the unbalance history as shown in Fig.7. When the unbalance force approaches zero then the model is in steady state, so the model which is loaded gravitationally is a steady state model.

Fig.8 shows in-situ model of 117 LW panel of Churcha mine after applying initial conditions and boundary conditions.

7.0 Results of the numerical modelling

This part discusses the numerical modelling results of vertical stress, stress distribution, and FOS of the depillaring workings

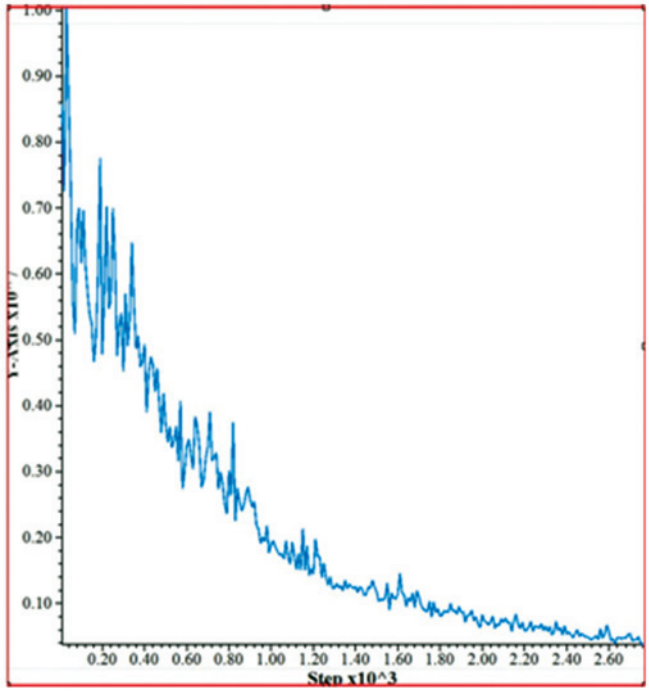


Fig.7 Unbalance force history

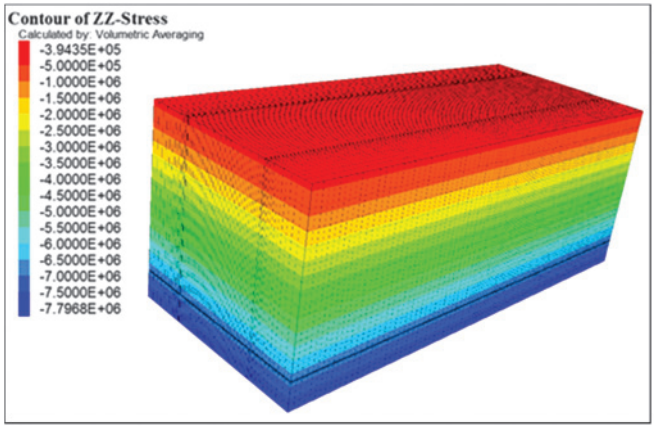


Fig.8 In-situ model - Churcha panel

by CM technology.

7.1 Developed Model of Churcha Mine

An in-situ model which is in steady state equilibrium undergoes extraction, i.e. formation of the pillars and galleries. Fig.9 shows the developed model of the 117 LW panel of Churcha mine.

7.2 Validation of the model

The stress on a pillar is calculated by the tributary area method, which is given by –

$$\text{Average stress } p = \gamma \times H\frac{(w+B)(L+B)}{w\times L} \text{ MPa} \quad \ldots (3)$$

Based on the above relation, for a rectangular pillars of length 44m and width 39m and gallery width 6m, the average stress works out to be 8.9 MPa.

Fig.10 shows the resulted model after development of the whole panel. As per the model, the stresses induced along the edges of pillar and in the centre of pillar are 12 MPa and 7.3 MPa, whereas the average stress is 9.65 MPa (approx.).

Figs.11 and 12 illustrate the zoomed view of developed galleries and 1st sliced fender of 1st pillar in the model. In Fig.11, high concentration of stress, almost 23 MPa, is acting on the edges pillars and 15 MPa on the sides of pillars which

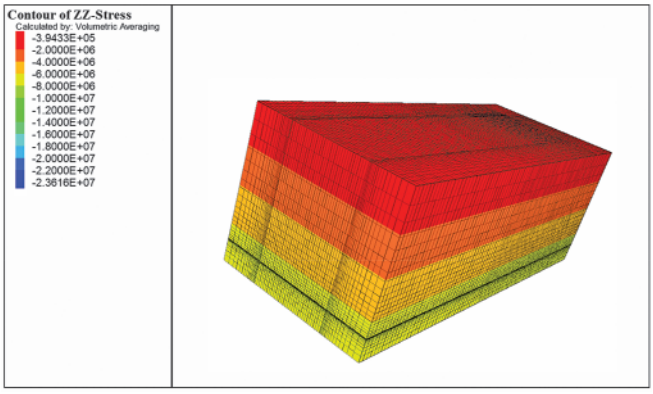


Fig.9 Churcha panel - developed model

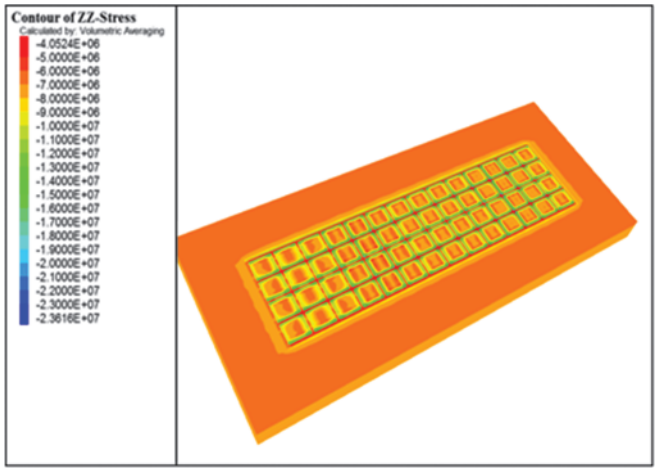


Fig.10 Resulted model after development – whole panel

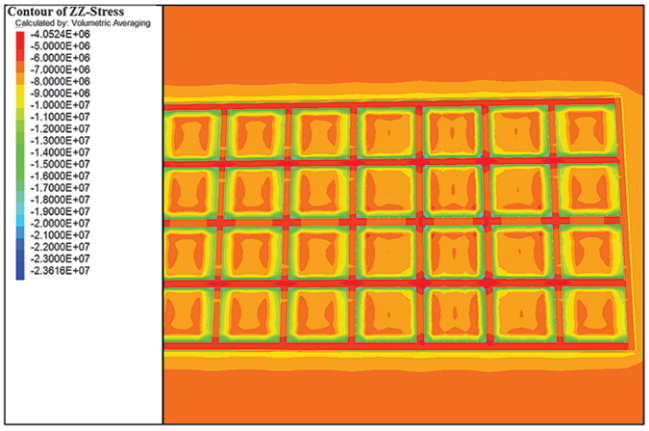


Fig.11: Zoomed view of developed galleries

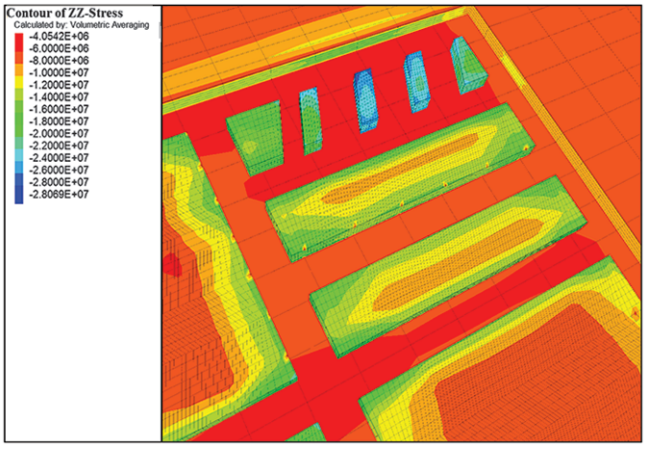


Fig.12: Sliced fender 1 of pillar 1

is close to stress concentrations on the field level.

The formula used for regular ribs is applied for calculating the strength for the ribs resulted in the CM panel. The strength of ribs developed by Sheorey and deliberated by (Jawed et al., 2013) is given as

$$\text{Strength of ribs} = 0.27\times\sigma c \times\frac{\sqrt{We}}{h^{0.86}} \text{ MPa} \quad \ldots (4)$$

With given effective width of first, middle (3) and last ribs to be 6m, 4m and 7m respectively, the strengths thereof may be calculated using the above formula to be 10 MPa, 9 MPa and 10 MPa respectively. On the other hand, stresses on ribs are obtained from the model. For example, the average stress on rib1 of the fender = 17 MPa.

FOS of the ribs of 1st, 2nd and 3rd fenders of each pillar may be worked out using the relation -

$$FOS=\frac{STRENGTH}{STRESS} \quad \ldots (5)$$

Figs.13 and 14 shows the models of 2nd and 3rd fenders respectively of 1st pillar and Fig.15 shows all pillars of the panel. Using the concept enumerated above, the FOS of all the ribs of all three fenders of a pillar has been worked out which are summarised in Table 3.

TABLE 3: ESTIMATION OF FOS OF DIFFERENT RIBS USING NUMERICAL MODEL

Fender No.	Rib No.	Calculated Strength (MPa)	Average stress obtained from the model (MPa)	FOS	Remarks on stability
Fender-1	Rib-1	10	17	0.6	Eventually fail
	Rib-2	9	18	0.5	Eventually fail
	Rib-3	9	22	0.4	Eventually fail
	Rib-4	9	17	0.5	Eventually fail
	Rib-5	10	14	0.6	Eventually fail
Fender-2	Rib-1	10	20	0.5	Eventually fail
	Rib-2	9	25	0.36	May fail instantly
	Rib-3	9	19	0.5	Eventually fail
	Rib-4	9	18	0.5	Eventually fail
	Rib-5	10	15	0.6	Eventually fail
Fender-3	Rib-1	10	19	0.5	Eventually fail
	Rib-2	9	25	0.36	May fail instantly
	Rib-3	9	25	0.36	May fail instantly
	Rib-4	9	18	0.5	Eventually fail
	Rib-5	10	15	0.6	Eventually fail

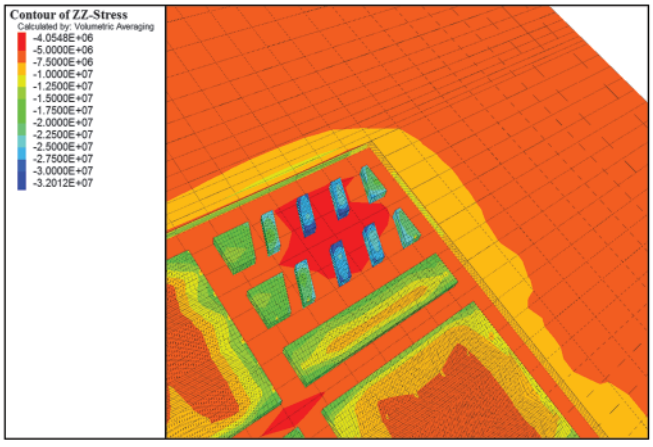


Fig.13 Pillar_1- fender_2 sliced

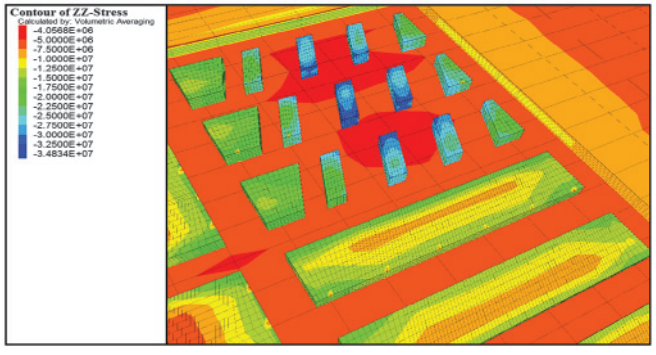


Fig.14: Fender_3 sliced

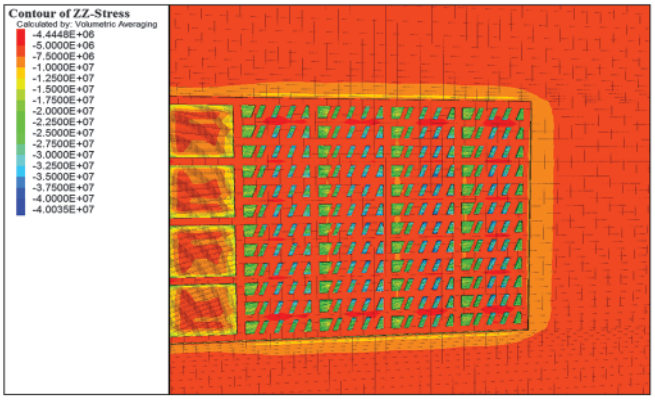


Fig.15 All pillars are extracted

7.3 STRESS DISTRIBUTION

As the extraction of pillar progresses, the different parts of fenders are subjected to different magnitude of vertical stress, depending on the distance from goaf edge. The pattern of vertical stress distribution on fender 1 and fender 2 of pillar 1 is shown in Figs.16 and 17.

Stress is high at small size pillar rib_1 and it decreases down to 15 MPa at greater size rib_5. Figs.18 and Fig.19 depict that stress distribution on the barrier during depillaring and development respectively. It may be seen that the stress concentration away from goaf and development gallery goes on decreasing and equal to in-situ stress -6.8Mpa.

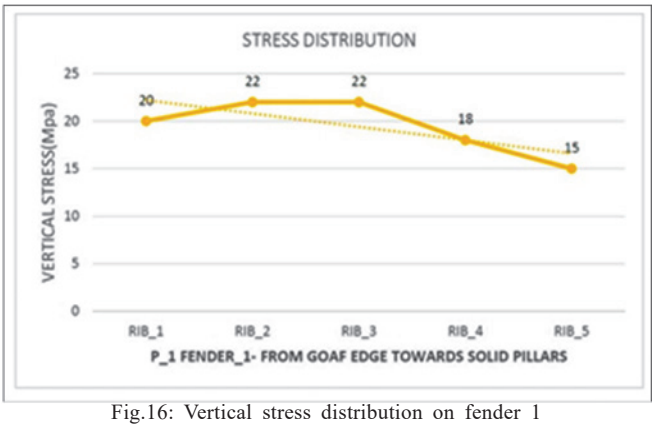


Fig.16: Vertical stress distribution on fender 1

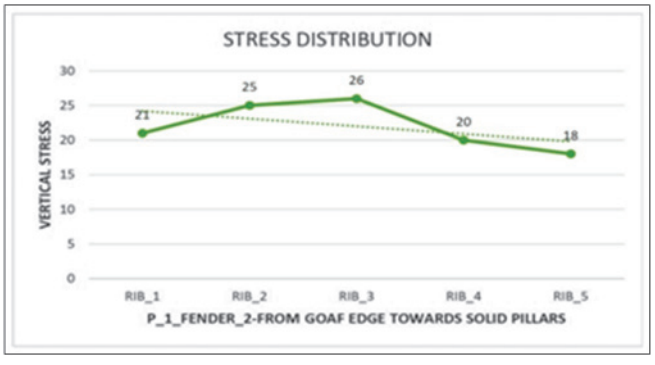


Fig.17: Vertical stress distribution on fender 2

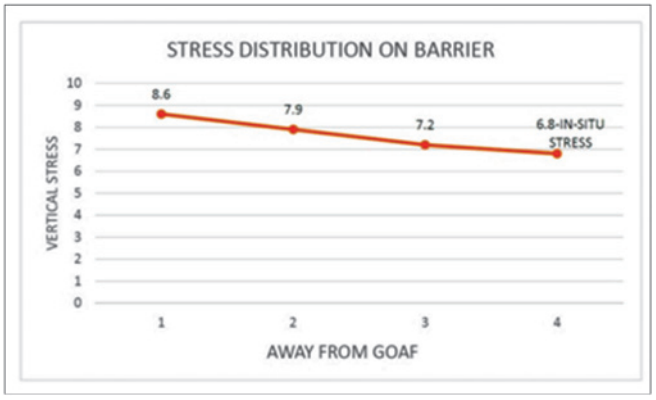


Fig.18: Stress distribution on the barrier during depillaring

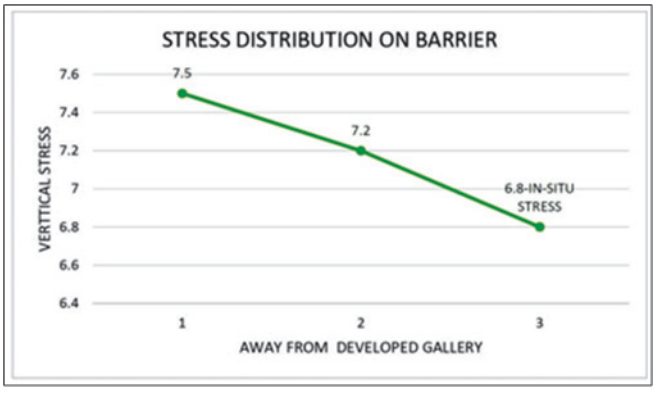


Fig.19: Stress distribution on the barrier during development

8.0 Conclusions and recommendations

The above numerical model leads to the conclusions that ribs at the center of a fender are under high stress concentration and may fail abruptly. Further, the snook at the galleries' intersection is adequate to withstand heavy load coming over the intersection. Even though small size ribs are there at another corner of the fender, these are not taking much load on it. The barrier may take the load from the ribs of small size and not making the small rib fail instantly. The model also indicates that the stress concentration on the area near the gallery in development workings goes on decreasing as we move away from it.

Based on the above conclusions, it is recommended that the rib at the corner of the fenders should be increased so that they withstand the load during slicing and judicious extraction of the pillars may be carried out if there is a problem of the roof caving. A better understanding of the immediate roof should be developed for proper designing of ribs and preventing delayed caving.

Acknowledgement

The authors are grateful to the management of Churcha mine, South Eastern Coalfields Ltd., for extending their support with the necessary information required for this paper. The views expressed in the paper are that of the authors and not necessarily of the organisations they belong to.

References

1. Agrawal, H., Singh, S. K., Mandal, P. K. and Singh, A. P. (2015): 3Dimensional numerical modelling: An effective enabler for CM deployment in coal seams. *Journal of Mines, Metals and Fuels*, 63(5–6), 111–118.
2. Chase, F. E., McComas, A., Mark, C. and Goble, C. D. (1997): Retreat mining with mobile roof supports. Proceedings of the New Technology for Coal Mine Ground Control in Retreat Mining, *NIOSH IC*, 9446, 74–88.
3. Christopher mark, tuchman j. rober. (1997). I c 9446 Proceedings/: New Technology for Ground Control in Retreat Mining. *NIOSH, IC* 9446.
4. Das, A. J., Mandal, P. K., Paul, P. S., Sinha, R. K. and Tiwari, S. (2018): Rock mechanics considerations for mechanised extraction of an inclined coal seam. Recent Challenges in Mining Industry (RCMI 2018), Organtzed by Mining Engineers' Association of India Dhanbad Chapter in Association with CSIR-Central Institute of Mining and Fuel Research Dhanbad - 826015, Jharkhand, India, 121–130.
5. Ghasemi, E., Ataei, M., Shahriar, K., Sereshki, F., Jalali, S. E. and Ramazanzadeh, A. (2012): Assessment of roof fall risk during retreat mining in room and pillar coal mines. *International Journal of Rock Mechanics and Mining Sciences*, 54, 80–89. https://doi.org/10.1016/j.ijrmms.2012.05.025
6. J.D.Inch, j.D. Stone, I.D.Brumby, C. J. B. (1980). The use of continuous miners in South African coal mines. *The Journal of The South African Institute of Mining and Metallurgy*, 5–21.
7. Jawed, M., Sinha, R. K. and Sengupta, S. (2013): Chronological development in coal pillar design for bord and pillar workings/ : A critical appraisal. 5 (January), 1–11. https://doi.org/10.5897/JGMR12.010
8. Kumar, A., Kumar, D., Verma, A. K., Singh, A. K., Ram, S. and Kumar, R. (2018): Influence of Overlying Roof Strata on Rib Design in Mechanised Depillaring. *Journal of the Geological Society of India*, 91(3), 341–347. https://doi.org/10.1007/s12594-018-0860-7
9. Lind, G. H. (2002a): Coal pillar extraction experiences in New South Wales. *Journal of The South African Institute of Mining and Metallurgy,* 102(4), 207–215.
10. Lind, G. H. (2002b): Key success elements of coal pillar extraction in New South Wales. *The Journal of The South African Institute of Mining and Metallurgy*, (June), 199–206.
11. Mandal, P. K., Kumar, R. and Sinha, A. (2006): State-of-art vis-à-vis Indian scenario of application of continuous miner based mass production technology.

Journal of Mines Metals and Fuels, (December).

12. Mandal, P. K., Singh, A. K., Kumar, N. and Singh, R. (2004): Strata Behaviour Investigations Of India's First Depillaring Face With Continuous Miner And Shuttle Car, *Minetech*, 25(6), 3–12.
13. Mark, C, Pappas, D. M. and Barczak, T. M. (1969): ground fall accidents in US coal mines. *NIOSH, IC* 9446.
14. Mark, Christopher. (2017): Ground control during pillar recovery with continuous miners. In Advances in Coal Mine Ground Control. https://doi.org/10.1016/B978-0-08-101225-3.00010-4
15. Mark, Christopher and Zelanko, J. C. (2001): Sizing of final stumps for sale pillar extraction. Proc. 20h Int. Conf. on Ground Control in Mining, Morgantown, WV, USA, 1–8.
16. Mishra, A. K., Mishra, A. K. and Rout, M. (2013): Blast-Induced Caving from Surface over Continuous Miner Panel at a 110m Cover in an Indian Mine. 1861–1870. https://doi.org/10.1007/s13369-012-0386-z
17. Mukhopadhyay, S. and Sharma, S. (2017): A case study illustration of the layout and support in an Indian coal mine with difficult roof condition where continuous miner is in operation. In Naj Aziz and Bob Kininmonth (Eds.), Proceedings of the 17th Coal Operators' Conference, Mining Engineering, University of Wollongong, 8-10 February 2017, (February), 8–10. Retrieved from http://ro.uow.edu.au/cgi/viewcontent.cgi?article=2310&context=coal
18. Ram, S., Kumar, D., Konicek, P., Singh, A. K., Kumar, R., Singh, A. K. and Singh, R. (2015): Rock mechanics studies during continuous miner based coal pillar extraction in Indian coalfields. *Transactions: A Technical Publication of the MGMI*, 111, 89–114.
19. Satyanarayana, I. and Budi, G. (2015): Evaluation of induced vertical stress during depillaring in blasting gallery panel workings. *International Journal of Geo-Engineering*. https://doi.org/10.1186/s40703-014-0002-z
20. Singh, A. K., Singh, R., Maiti, J., Kumar, R., & Mandal, P. K. (2011): Assessment of mining induced stress development over coal pillars during depillaring. *International Journal of Rock Mechanics and Mining Sciences*, 48(5), 805–818. https://doi.org/10.1016/j.ijrmms.2011.04.004.
21. Singh, R., Mandal, P. K., Singh, A. K., Kumar, R., & Sinha, A. (2011): Coal pillar extraction at deep cover: With special reference to Indian coalfields. *International Journal of Coal Geology*, 86(2–3), 276–288. https://doi.org/10.1016/j.coal.2011.03.003
22. Singh, S. K., Agrawal, H. and Singh, A. P. (2017). Rib stability: A way forward for safe coal extraction in India. *International Journal of Mining Science and Technology*, 27(6), 1087–1091. https://doi.org/10.1016/j.ijmst.2017.06.007
23. Vervoort, A. and Jack, B. (1992): Analysis of sidewall fracturing and spalling during. *The Journal of The South African Institute of Mining and Metallurgy*, 92 (January), 3–11.
24. Churhca Mine Management and Annual Safety Week Report, Churcha Mine (2016)
25. Annual Report, 2019-20, Official Website, Ministry of Coal, Govt. of India.

JOURNAL OF MINES, METALS & FUELS

Special Issue on

BAUXITE RESOURCES OF GUIZHOU PROVINCE IN CHINA

For copies please contact:
The Manager
Books & Journals Private Limited
Moon Plaza (2A, 2nd Floor), 62 Lenin Sarani, Taltala, Kolkata 700013
e-mail: bnjournals@gmail.com; pradipchanda@yahoo.co.uk;
www.jmmf.info • Mob: +919239384829 / 9903463829