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Rock mechanics challenges of depillaring at deep cover

Underground coal mining at deeper cover encounters difficult underground environment due to increase in gas content and rise in temperature. Transition of a mining practice from shallow to high depth cover encounters a big change in the rock mass characteristics and the stress condition becomes more complex. At higher depth of cover, the excavation starts encountering stress control regime rather than structural control behaviour of the rock mass. Mechanisation and automation of underground mining activities is a solution to improve the performance of deeper mines but the approach should match with the rock mass and stress conditions of the site. Since inception, CIMFR (formerly, CMRI) is continuously working to understand behaviour of the rock mass through laboratory testing, field investigations and study on simulated models. Obtained experiences during these investigations are observed to be of strategic importance during application of a modern technology to improve practical mining conditions. This paper reviews rock mechanics aspects of different mechanized pillar extraction approaches during mining of a deep seated coal seam and, also attempts to present an appraisal of some of the recent technical developments to overcome the challenges of a deep underground coal mining.

Introduction

In coming days, coal mining industry in the country is going to have unprecedented growth and coal will maintain its leading role to meet the primary energy consumptions in India due to its proven geological reserve. Coal demand of 473 million tonnes in the fiscal year 2006-07 is likely to reach up to 1267 million tonnes in the fiscal year 2024-25 with 8% growth in GDP. Future coal mining in India is to encounter, relatively, deeper excavations in difficult rock mass and hostile underground environmental conditions. Presence of different unknown parameters in assessing rock mass behaviour at deeper cover may lead to strata control problems, while the increase in temperature and gassiness (Sinha, 2008) of the coal seam (Fig.1) is a potential threat for underground mine disaster. These problems of a deep seated coal seam make it challenging for mining. Here mechanization and automation of the mining process is of great importance to improve safety along with production and productivity under the arising difficult geo-mining conditions of a deep seated coal seam (Sinha et al., 2006). Developed countries have adopted this approach to counter the above mentioned menace of deep coal mining. The opening up of the economic policy of the country makes it easier to import and implement the mechanization and automation approach for deep coal mining in India. In fact, a modern mining approach will provide strength to our coal mining industry to meet energy security challenge and to counter the global productivity competition.

However, it is not straight-forward to apply foreign technology for coal production in India due to uniqueness of our coalfields. Coal mass and the surrounding rock mass of Indian coalfields are, generally, strong and massive in nature and the available information about the associated stress fields is quite scanty. Considering different uncertainties in quality and character of the coal deposits and frequent changes in geo-mining conditions, the role of a scientific investigation becomes even more important for enhancing quality, safety, production and productivity through mechanization and automation. On the basis of our long association with considerably large number of underground coal mining faces, it is realised that the experience of rock mass behaviour is an important input for a successful adoption of the modern approaches of coal mining in our coalfields. Discussing some experienced rock mechanics aspects of pillar extraction, this paper briefly presents important strata control issues for a successful adoption of the modern technology for optimal extraction of deep seated developed coal seams in India.

Mechanised pillar extraction in India

In India most of pillar extraction exercise is still done by conventional method using drilling and blasting with some high speed coal evacuation/transportation system. This yields, relatively, low production and productivity. However, the demand of coal is increasing sharply every year. To cope

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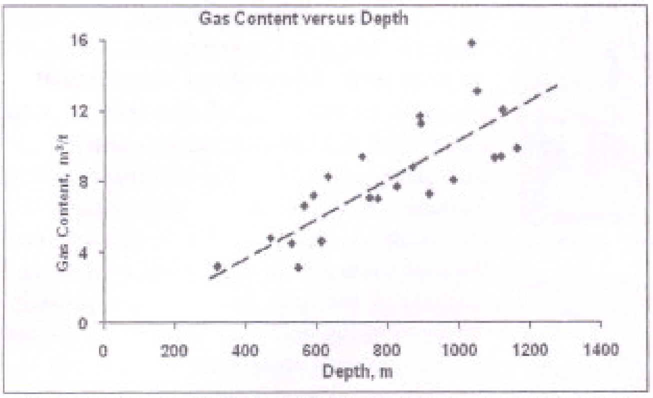


Fig.1 Relationship between gas content and depth of coal seams (after Sinha, 2008)

up with this high demand of coal, Indian coal mining industry has recently implemented continuous miner for pillar extraction in three mines. In India the depillaring with CM and shuttle car is termed as 'mechansied depillaring' which is quite commonly practiced in USA, Australia and South Africa.

Country's first fully mechanized depillaring face of Anjan Hill mine of South Eastern Coalfields Ltd. (SECL) experienced a productivity of over 12 tonnes per man-shift during depillaring without encountering any strata control problems. The successful application of continuous miner (CM) and shuttle car along with roof bolt as systematic support (SSR) has shown the direction to tackle the productivity problem of underground pillar mining. In-situ performance evaluation of the technology (Singh et al., 2004) by CMRI (Now CIMFR) showed outstanding techno-economical results of the trial in the depillaring panels of Anjan Hill mine, Chirimiri Area, SECL. Here, strata control study by CIMFR demonstrated that the application of resin grouted, pre tensioned, stiff and high capacity roof bolts as SSR, including the breaker line support (Fig.2), can effectively arrest the strata movement during the caving. The second application of the technology is made at Tandsi colliery, WCL, where the method adopted one of the highest support density (utilizing high capacity roof bolts and Flexi-bolts) for the SSR (Mehta and Malhotra, 2004). Third application of the technology is made at VK-7 incline mine, SCCL but encountered strata control problems in the beginning (before main fall), probably, due to misunderstanding about the nature of overlying strata.

These are the three field trials of the technology in the country till date. The first two applications of the technology were done under moderate and easily caveable roof strata and did not experience any serious strata control problems. The third attempt of CM technology at VK-7 incline was made at 377 m depth of cover and under massive roof strata, which could not succeed due to strata control problems (Frith Report, 2006). However, application of the CM technology in USA and Australia for pillar extraction is quite often and a review of application of the technology at higher depth may provide some guidance to our efforts in adopting this approach.

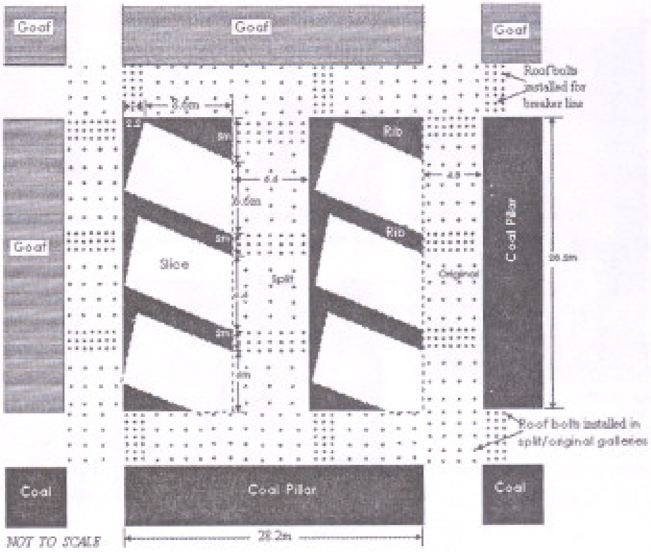


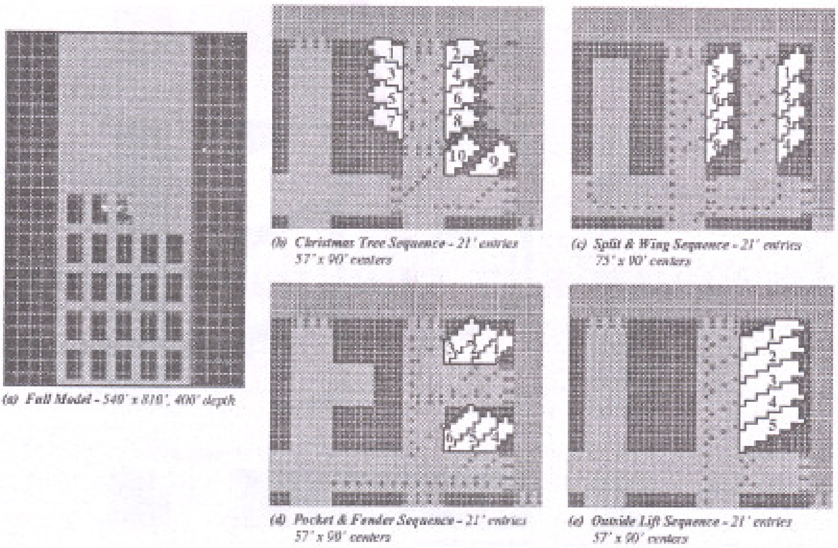
Fig.2 Systematic and breaker line supports placement with respect to slice position during depillaring by continuous miner and shuttle car combination at Anjan hill mine

Available options

Existing scenario of coal reserve and mining trend in India suggests that pillar recovery at higher depth cover is an important emerging issue for the coal industry. Coal mining activity at deeper cover is likely to intensify in the future because the shallower deposits are exhausting, which will, ultimately, compel the coal mining industry to go at deeper cover. At greater depths, the size of pillars becomes too wide to be fully extracted with single pass pillaring techniques. Here pillar splitting before extraction becomes the only alternative if the pillars are to be fully extracted. However, the splitting requires support placement which may hinder the speed of production. In developed nations, a depillaring panel adopts pillar extraction using either the Christmas tree or split and fender extraction methods (Mark et al., 2002). Out of these two approaches, Christmas tree is usually the most favoured by operators due to its fast production rate because it does not require place changes and bolting at the time of pillar extraction. Another approach for pillar extraction is the pocket and wing method, which also requires place changes and bolting. It is observed during the practice that if large pillars require splitting, then the split and fender method is preferred (Fig.3) because it minimizes gob exposure as compared to the pocket and wing technique.

Rock mechanics

It is rational to compare the Christmas tree approach with the outside lift method from rock mechanics point of view. In Christmas tree method, the machine cuts coal from, both, the left and the right of pillars, while with outside lifts, only one pillar is mined at a time. A comparison of these two methods finds that the Christmas tree method is more risky than outside lifts because:



(a) Full Model - 540' x 810', 400' depth

(b) Christmas Tree Sequence - 21' entries 57' x 90' centers

(c) Split & Wing Sequence - 21' entries 75' x 90' centers

(d) Pocket & Fender Sequence - 21' entries 57' x 90' centers

(e) Outside Lift Sequence - 21' entries 57' x 90' centers

Fig.3 Model of different retreat cut sequences for pillar extraction (after Mark et al., 2002)

- Mining of a wider and unsupported span;
- Machine spends, relatively more time below the span to complete, both, right and left slices; and
- It is difficult for the continuous miner (CM) operator to establish an optimum location for the remote operation for either the left or the right slices.

However, during practice of outside lift method, handling of a cutting machine is done under the shadow of a solid pillar. Disadvantages of this method are:

- This method is difficult to be used in wide pillars without leaving large remnant fenders of coal, and
- Machine is deployed here for deeper cuts and, therefore, it becomes a difficult task to withdraw the machine if it is trapped under a roof fall while extracting a slice.

In India, most of the developed pillars at deep cover are, relatively, wider, which are difficult to be fully extracted by a single pass pillaring technique like Christmas tree method. Even the scope of outside lift method is limited for these wider pillars of deeper deposits. These pillars need to split before slicing for which split and fender method may be a better option.

Percentage of extraction is kept low at the time of pillar formation because entire weight of the overburden is supposed to be carried by these pillars. Further, generally, there is a considerable time gap between pillar formation and their final extraction. Therefore, these pillars are designed for long term stability with adequate width to height ratio (w/h). Even for these stable pillars, new stress equilibrium is established after their formation. Here, strata control concern is, mainly, related with the stability of immediate roof above the entry. Removal of a pillar disturbs the equilibrium of pillar formation. A wider void, created due to the pillar removal, enhances the chances of instability. It is not possible to carry the full weight of the overburden by applied supports. Roof strata experience additional stresses and deformations due to further increase in the size of the void due to extraction of other pillars. Creation of sufficient width of the void due to pillar extraction will cause break and caving of the roof strata. At this stage, interaction between the roof strata and support (both, applied and natural) is the area of interest, especially during working below a difficult roof. Stress and deformation measurements (Singh et al., 2006) in and around a depillaring face below difficult roof shows that the 5-10 m zone of rib side remains critical and are vulnerable for dynamic loading (Singh et al., 2001) as shown in Fig.4. Under this condition, it is always better to apply a remote device to win the coal from this critical zone, which can easily be achieved by a CM face. However, even after application of a remote coal winning machine, the design of slices and ribs becomes an important factor for the success of the mechanisation. There is a need to have a stump to face the gallery junctions during slicing of the stooks. W/h ratio of these stumps should be kept 2 as per the NSW norms of depillaring (Frith Report, 2006). The effectiveness of this stump should be diluted during retreat if the conditions permit. This dilution may be adopted for the initial few stooks and, latter, for distressed conditions of the area after main fall. However, the dilution should not be attempted against overhanging goaf.

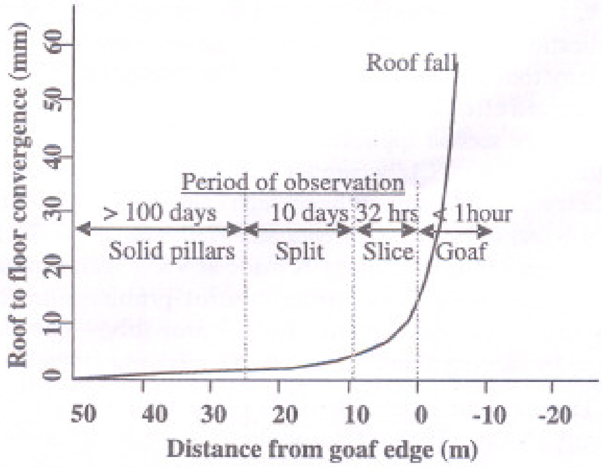


Fig.4 Variation of roof to floor convergence with goaf edge distance of an Indian depillaring face along with timeperiod of the observation

Pillar extraction in USA

In USA, both, the regulatory agencies and mining industry have always been very positive in applying a new technology to improve safety and arrest strata fall risk during pillar recovery by a fully mechanised depillaring technology. At least, two roof support technologies: mobile roof supports (MRS) and high capacity, pre-tensioned, stiff and resin grouted roof bolts have shown promising results. Considerable reduction in roof fall problems is observed due to adoption of MRS (Mark et al., 2002). While, in presence of suitable geo-mining conditions, application of high capacity, pre-tensioned, stiff and resin grouted roof bolts as SSR provided some additional advantages in this endeavour. It is the complex interaction between overlying strata and support (both, natural and applied) which determines suitability of the approach to control roof fall and is yet to be quantified to fit in any given geo-mining condition. However, different depillaring experiences with these approaches are of vital importance and, at moment, these experiences are the bases for present decisions. Studies conducted in USA during the past decade, have identified following "risk factors" (Mark et al., 2002) that can be used to evaluate pillar extraction plans:

- Cut sequence
- Depth of cover
- Roof quality
- Final stump
- Timber or mobile roof supports
- Age of workings
- Roof bolting

A detailed consideration of all these risk factors categorises the involved stabilities into two parts during pillar extraction, which are:

Global stability

This stability considers prevention of section-wise pillar failure.

Local stability

This stability considers prevention of roof falls in the working area.

The parameters involved with local stability (Mark et al., 2002) are quite important for working below weak and fragile strata. Adoption of a mining approach to suit the site conditions and application of efficient cutting and support system (Mehta and Malhotra, 2004) are important to control the problems of local stability. Global stability plays significant role for working under competent roof strata and consists of mainly three problems: Pillar squeezes, massive collapses and pillar bumps. These problems are more relevant for Indian coalfields and, accordingly, discussed below under heading experience of Indian coalfields.

Pillar extraction in Australia

The trend in Australia is to move away from bord and pillar mining and to adopt almost 100% supported face i.e. longwall technique for extraction of coal by underground mining. However, a coalfield like New South Wales (NSW) of Australia has a successful history of pillar extraction since last 70 years. A number of depillaring methods ranging from rib pillar methods (such as Wongawilli system) to the more recent pillar stripping techniques have been practiced in different mines. Lind (2002) has presented the experience of visiting seven underground mines of NSW. Out of these seven mines, four adopted complete pillar extraction approach and the other three adopted partial extraction approach. The depth cover of, at least, one full pillar extraction (Mine A) was 420 m while the depth of one partial pillar extraction (Mine F) was 300 m. Recent pillar extraction in NSW was conducted using pillar stripping techniques (similar to the extraction methods used in USA) rather than using specialist rib pillar techniques. Mobile breaker line support (MBLS) was found to influence overlying strata up to 18 m, while the 20 m overlying strata was observed to be the influencing factor for the caving behaviour. This indicated that MBLS are a successful means to control immediate overlying strata during depillaring.

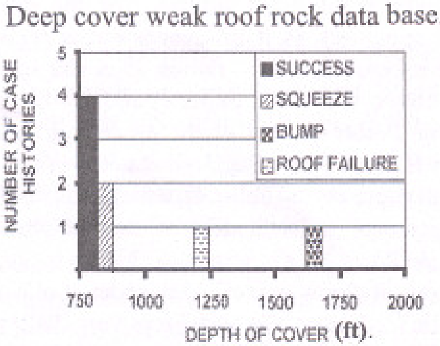
Basics of the depth variation

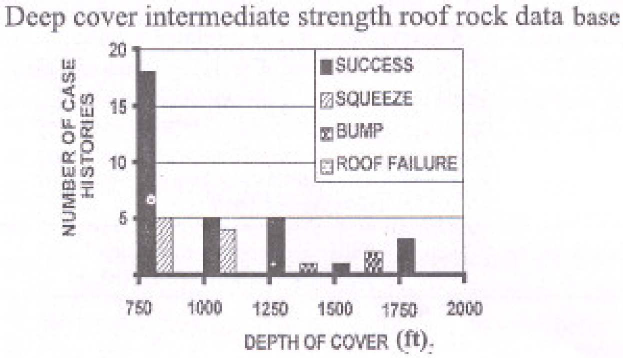
Depth of cover is of great interest for the design of underground structures as it influences stress regime and nature of the rock mass. The variation of in situ stress field with depth cover was well experienced by the mining engineers even before advent of the modern in situ stress concept. This is the reason of age-old concept of increase in pillar size with depth cover (Table 1), which is a well familiar example of practical understanding of the phenomena. The rock mass at shallow cover is, generally, highly fractured and carries low value of elastic modulus. Dependence of horizontal stress on elastic modulus of the rock keeps very shallow cover regime almost free from high stress problem, while the deeper cover rock often encounters problem related with high stress field. Pillar bumps, excessive roof falls, spalling/crushing of natural support and floor heaving are the most likely problems of deeper cover mining.

TABLE 1: PILLAR SIZE VARIATION AS PER INDIAN COAL MINES REGULATIONS, 1957

Depth cover, m	Pillar size (centre to centre) for different roadway widths (B), m			
	B=3.0	B=3.6	B=4.2	B=4.8
Below 60	12	15	18	19.5
60 to 90	13.5	16.5	19.5	21
90 to 150	16.5	19.5	22.5	24.5
150 to 240	22.5	25.5	30.5	34.5
240 to 360	28.5	34.5	39.5	45
Above 360	39.5	42	45	48

Although it is very difficult to have a clear demarcation line for deep cover but Deshmukh (1987) defines it to be 200 m. This demarcation line is based on experience of coal mining in India. During recent field studies by CIMFR, it is observed that if the cover of a depillaring panel exceeds 200 m, natural supports around the face, generally experiences side spalling. Our this practical experience of Indian depillaring panels also supports 200 m as demarcation line for deeper mine. This assumption also works well for estimation of nature of mining induced stress development (Singh et al., 2006). However, American experiences for the continuous miner faces are bit different and, as per Chase et al. (2002), if the overburden exceeds of 750 ft (228.6 m) then the property is called to be located at deeper cover. To develop appropriate design guidelines for depillaring at deeper cover in USA (Chase et al., 2002), geo-technical data from 97 panels of 29 mines in 7 states were collected. The analyses of these data indicated that squeezing of pillar were the most likely failure mode where the depth was less than 1,250 ft (381 m), but bumps predominated in the deeper cover cases (Fig.5). Here, failed panel design case histories attributed to roof falls for different depth cover, which were documented under, both, weak and competent immediate roof strata. On the basis of this experience, it was observed that it is not feasible to mine the coal by bord and pillar technique under weak roof conditions at a deep cover of high stress regime.


Deep cover weak roof rock data base.


Deep cover intermediate strength roof rock data base

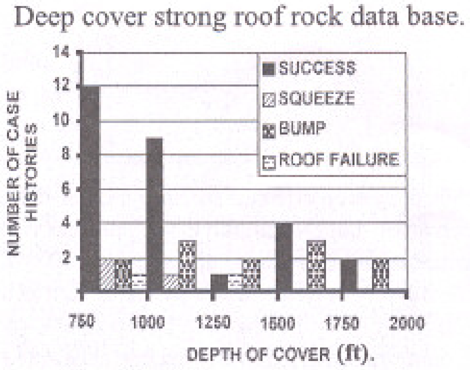

Deep cover strong roof rock data base.

Fig.5 Analysis of depillaring performance at deeper cover for different roof types (after Chase et al., 2002).

Experience of Indian coalfields

Problems associated with the global stability (Mark et al., 2002) are often experienced during underground coal mining in India, which depends on a number of factors as explained below:

PILLAR SQUEEZES

During depillaring, when the pillars are too small to carry the loads applied to them, squeezing of pillar occur. Pillar size given by coal mines regulations (CMR, 1957) of India provide stable pillars of considerably high w/h ratio. But during a depillaring operation, the pillars ahead of the face are splitted resulting smaller pillars/stooks facing goaf line. Once a small pillar squeezes and fails, the load is gradually transferred to the adjacent pillar resulting in failure of pillars in rhythmic sequence. This type of failure of smaller pillars is encountered under competent roof strata. During depillaring of Sonachora seam at Lachhipur colliery, ECL, such rhythmic failure of 52 stooks/pillars (each 7.5 m × 7.5 m, corner to corner and bord width 4.5 m) took place due to pillar squeezes (Singh et. al., 1996).

MASSIVE COLLAPSES

When roof strata overhang over a large area of the goaf, chances of massive collapse is there because the fall involves large areas. This collapse may cause wind blast for an empty lying goaf and may also become a source of dynamic loading of pillars. A study conducted in USA suggests that massive collapses occur when the pillar width-to-height (w/h) ratio is 3.0 or less and the safety factor (SF) is less than 1.5 (Mark et al., 2002). More or less, similar approach is adopted for Indian coalfields but, sometimes, even these simple norms are inevitably not followed. If the pillars/stooks facing goaf line are not strong and stiff enough, dynamic loading of pillars during these collapses may cause overriding. For a thick coal seam already developed along roof horizon, superimposed bottom section development based underground extraction of total thickness of this thick coal seam in single lift by blasting gallery (BG) method encountered overriding problem [Singh, 2004(a)].

PILLAR BUMPS

A study in USA (Chase et al., 2002) shows that nearly 95% of the observed bumps cases occurred at depths greater than 1,000 ft (≈305 m). Here sudden outbursts of coal and rock occur due to high stresses in a pillar. Rupture of highly stressed rock mass without warning becomes a safety problem and, therefore, a number of approaches have been devised (Haramy and McDonnel, 1988) and (Kidybinski, 1981) to assess the bump-proneness. Woking of Dishergarh seam, Chinakuri mine, ECL at nearly 650 m depth of cover experienced bump problems. Accordingly drill-yield test and energy index determination are attempted (Singh et al., 2006) to identify the highly stressed zones and to understand bump liability.

In last fifty years, CIMFR conducted extensive investigations in field and laboratory to formulate different indigenous design norms. A number of such successful developments are being widely practiced by our coal mining industry. However, for the changed situation of deeper cover, necessary adaption in these norms is also in progress as per the observed nature of the rock mass. Some typical examples of empirical formulations based on field measurements are given below:

PILLAR STRENGTH

CIMFR, first, developed pillar strength formula (Sheorey et al., 1987) on the basis of correlation of different parameters during a long-term study of failed and stable cases of our coalfields. However, this formula encountered some problems when compared to the actual field observations. To remove this mismatching, the in situ stress conditions of these sites were considered (Sheorey, 1992) through depth cover incorporation and the resulted pillar strength (S) formula is:

$$S = 0.27 \times \sigma_c \times h^{-0.36} + (H/250+1)\,(W_e/h-1)\ \text{MPa} \quad \ldots \quad (1)$$

Where:

σ_c = Uniaxial compressive strength of coal in MPa

h = Working height in m

H = Depth of cover in m

W_e = Effective pillar width = 4A/Pc

A = Area of pillar = L1 × L2 and

P_c = Perimeter of the pillar (corner to corner) = 2 × (L1 + L2)

L_1 = Length of the pillar (corner to corner) and

L_2 = Width of the pillar (corner to corner).

Most of the pillar strength formulae, developed by other countries, failed to consider the observed change in compactness characteristic of rock/coal mass with depth cover, which is well considered and addressed in this formula to explain the actual condition of the site.

MINING INDUCED STRESS

Safety of a pillar basically involves two parameters: (a) strength of the pillar and (b) mining induced stress on the pillar. In practice, assessment of mining induced stress on the pillar is rather more difficult than the determination of the pillar strength. As soon as a pillar is formed in a coal seam, mining induced stress develops over it which, initially, remains confined over the edge of the pillar and its value stays small. Depillaring adopts a number of manners of pillar extraction but all these manners, basically, reduce the size of pillars around the extraction line resulting corresponding increase in width of the excavation. An increase in the width of the excavation results increase in value of the mining induced stress. Once the value of the induced stress exceeds the uniaxial compressive strength of the coal, some side deformation/spalling of pillar is observed and the position of the peak value of the induced stress shifts inside of the pillar. In fact, the arrest of increased value of mining induced stress is due to tri-axial state of the loading condition inside the pillar. The most obvious sign of high value of mining induced stress at deeper cover or under massive roof strata is spalling from the pillar/stook surfaces. Further increase in the stress pushes the position of the peak value of the induced stress inside the pillar which brings even core of the pillar under its influence before failure. Lunder and Pakalnis (1997) and Fang and Harrison (2002) have described the progressive stages of degradation of a pillar under increasing high value of stress. Observed profiles of mining induced stress development over a pillar/stook at different stages of loading during depillaring under massive and weak overlying strata are shown in Figs. 6 and 7 respectively. It shows that the core of a stook remains intact during caving of weak roof strata but caving of massive roof may lead to overriding. In fact, the depillaring below massive strata was planned with stowing and, therefore, a stook (7.5 m × 7.5 m, corner to corner) left inside stowed goaf did not experience failure due to presence of side confinement (Singh et al., 1996). Here value of induced stress influence core of the stook but stabilised with an uniform value all over the stook. However, in absence of the stowing material, caving of the competent roof strata in the same panel caused crushing a stook of 7.5 m × 7.5 m, corner to corner, size. Before crushing, core of the stook experienced the peak value of induced stress.

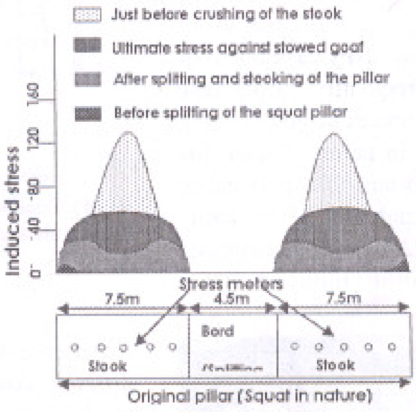


Fig.6 Stress concentration over stooks facing different stages of depillaring below

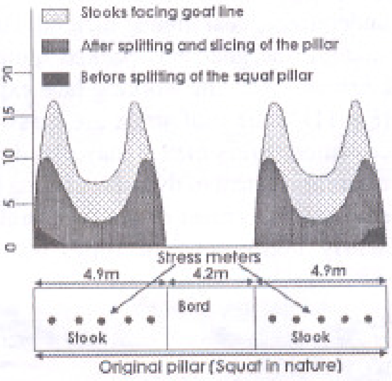


Fig.7 Stress concentration over stooks facing different stages of depillaring

Study of mining induced stress development during depillaring is done at twenty depillaring faces with depth cover (average) range variation from 44 to 244 m. To explain the behaviour of the stress development, the results are divided into two parts on the basis of the practical field experience and the demarcation line is considered to be 200 m. Accordingly, Figs. 8 and 9 provide general model of mining induced stress development with respect to goaf edge distance of Indian coal mine for depth cover < 200m and depth cover > 200m respectively. Although these two figures represent general trend of the stress developments at two cover range, it is important to note that the stress development is site specific.

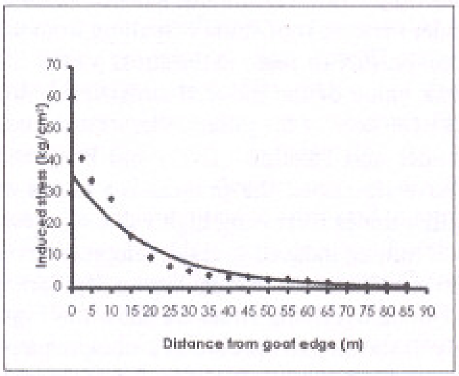


Fig.8: Mining induced stress variation for Indian Coal Mines (Depth <200m)

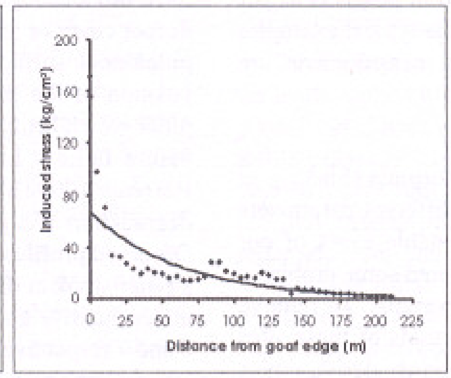


Fig.9: Mining induced stress variation for Indian Coal Mines (Depth > 200m)

Overlying strata behaviour

Indian coalfields experience wide variation in the characteristics of the overlying strata, which have been categorised in different ways for different purposes. Even at deep cover, it is difficult to have any "typical" roof strata, which can be used as a benchmark to decide different design strategy. Field experience shows that it is very difficult to extract pillars, developed below very weak strata at deep cover due to excessive roof failure (Fig.10) under high stress condition. In fact, the behaviour of overlying roof rock mass has got considerable influence over the performance of an underground coal mining method. For an easily caveable roof stratum, the goaf gets packed quite frequently during face advance, while the working face experiences large overhang (Fig.11) if the roof strata are massive in nature. Under this condition, stress meters may play important role to visualise nature and extent of dynamic loading (Singh et al. 1996) during enmasse movement of the roof strata. A careful monitoring, nearly continuous in time, of mining induced stress development over pillars may help in estimating the time and period of occurrence of the dynamic loading. Results of a field monitoring of mining induced stresses (vertical) at two different sites are presented in Fig.11 to show the influence of overlying roof strata over nature and amount of the stresses.

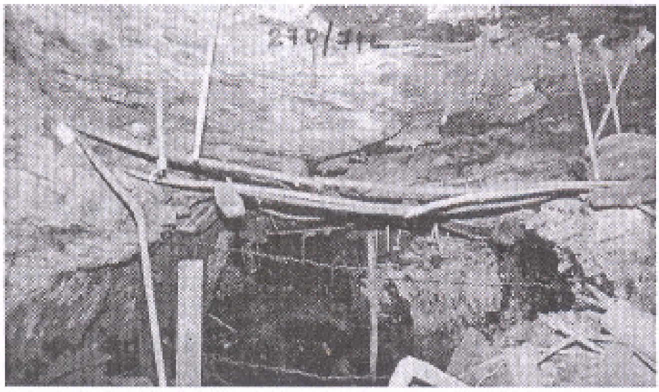


Fig.10: Roof instability during development of galleries at deeper cover

For a sub-critical span of the extraction, the good support resistance efficiency of a rib plays positive role for mining operation at face. But, as soon as the width of extraction becomes critical, these ribs face a situation of crushing leading to a chance of dynamic loading over pillars/stooks facing the goaf line. The presence of massive roof strata at this junction of excavation may pose serious problems if the pillars of low w/h ratio are facing goaf line.

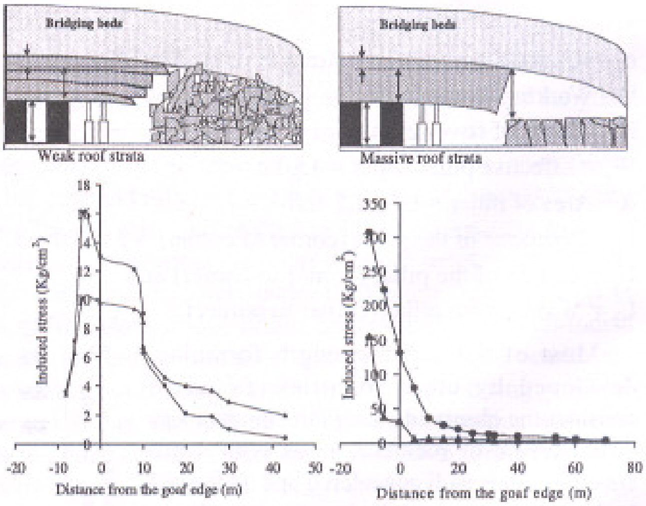


Fig.11 Observed variation of mining induced stress (vertical) over a pillar during depillaring under easily caveable/softer and massive/strong overlying roof strata

Cuttability of coal

Experience of analysis of different core samples procured from different coalfields of the country for the study of physico-mechanical properties and rock quality designation (RQD) shows that the compactness and intactness of the strata increases with depth cover. This makes it difficult to cut by machine, at least during development stage. However, at relatively deeper cover, the increase in width of excavation during final extraction induces high value of mining induced stress. Once the value of induced stress increases the uni-axial compressive strength of coal, the working face starts encountering spalling and the cutting becomes, relatively, easier (Sikora and Major, 1988). Further, the amount of coal affected by igneous intrusion increases with increase in depth cover. A study by Sengupta (1980) shows that the ratio of coal:jhama decreases considerably (Table 2) for deeper coal seams. For mechanised cutting of coal, the change in strength domain from coal to jhama near a jhama/dyke contact adversely affects the cuttability and also the life of the cutting tools. CIMFR studied (Singh et al., 2002) the influence of intruded igneous materials over the cuttability of the coal mass for an efficient mechanised gallery drivage in coal seams consisting of igneous intrusions.

Table 2: The ratio of coal:jhama at different depth levels in the Jharia coalfield (after Sengupta, 1980)

Depth range (m)	Ratio (coal:jhama)
150 - 300	5.8:1
300 - 600	4.8:1
600 - 900	1.9:1

On the basis of physical inspection of exposed area in a gallery, the coal mass near an igneous intrusion band is divided into four zones; called as (1) normal, (2) pulverized, (3) Jhama and (4) mixed zone excluding the dyke/sill. Influence of intruded igneous materials over the in situ strength of the coal mass was studied by Schmidt hammer while the influence over cuttability of the seam was studied through monitoring of current drawn by roadheaders during mechanised gallery drivage in coal seams consisting of igneous intrusions. Both, strength and cuttability across the band of igneous intrusion were found to be highly dependent upon the proximity and extent of the intrusion. In fact, requirement of current for gallery drivage across the coal mass with igneous intrusion was observed to be quite high in comparison with that required for the normal coal mass. To understand this phenomenon in detail, a number of samples were collected from the coal-intrusion interface and were subjected to laboratory tests for physico-mechanical properties along with cuttability testing with a drag bit type coal plough rig. The laboratory study showed wide variation in cuttability properties (Fig.12) of different samples collected from different zones of the affected coal mass surrounding the intrusion band.

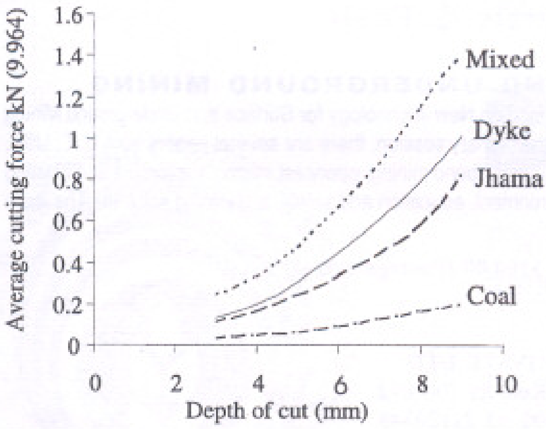


Fig. 12: Variation of average cutting force to cut normal coal mass, jhama, mixed mass and dyke during laboratory cuttability testing with a drag bit type coal plough rig.

Conclusions

There is a need of quantum jump in underground coal production in India. Success of mechanisation and automation of the underground coal mining process is must to achieve this jump. However, the increasing depth of coal seams in the country likely to offer difficult conditions for the mechanisation. A good knowledge of geo-mining conditions, understanding of rock mass behaviour and a control of underground environmental conditions are significant issues for a successful adoption of a mechanised mining operation for extraction of deep seated coal seams. It is observed that the role of rock mechanics investigations are, relatively, more important but intense at deep cover. On the basis of long-term association with considerably large number of underground coal mining faces, CIMFR (formerly CMRI) is continuously working to understand the behaviour of the rock mass through laboratory testing, field investigations and study on simulated models. These efforts have resulted in derivations of important design norms/relationships to improve practical mining, which may provide key inputs for the success of a mechanised underground mining of deep cover coal seams.

Acknowledgement

Authors are highly obliged to the Director, CIMFR, for his permission to publish this paper. The views expressed in this paper are those of the authors and not necessarily of the institute to which they belong.

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Printed by A. K. Ghose at The Indian Press Pvt. Ltd. 93A Lenin Sarani, Kolkata 700 013 and published by him for Books & Journals Pvt. Ltd. from 6/2 Madan Street, Kolkata 700 072.