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A NOVEL METHOD FOR UNDERGROUND EXTRACTION OF A CRITICALLY THICK COAL SEAM STANDING ON PILLARS AND THE DEVELOPMENT MADE ALONG THE ROOF HORIZON

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अन्तर्निष्ठ भू-तकनीकी कठिनाइयों के कारण पूरे विश्व में मोटे कोयला संस्तरों के भूमिगत खनन से बहुत कम उत्पादन स्तर मिलता है। चाल (roof) के साथ स्तम्भों (pillar) पर विकसित अति (critically[1]) मोटे संस्तरों के मामले में यह समस्या और भी गम्भीर हो जाती है। ऊपरी भाग का प्रथम खनन निचले भाग, अर्थात् फर्श के साथ के कोयले के सुरक्षित खनन को जोखिम में डाल सकता है। कोयला संस्तर के सुरक्षित, कुशल और किफायती खनन हेतु एक बार में पूरे कोयला संस्तर के धंसान (caving) की मदद लेते हुए एक तिर्यक विकास की परिकल्पना की गयी है। निचले भाग के तिर्यक विकास की परिकल्पना अनुरूपण मॉडलों (simulated models) पर किए गए प्रयोगशाला परीक्षण द्वारा समर्थित थी और इसका प्रयोग कोयला संस्तर की पूरी मोटाई को एक ही बार में खनित करने योग्य लगता था। तथापि तिर्यक रूप से विकसित अति मोटे कोयला संस्तरों के निखनन से जुड़ी संस्तर नियंत्रण समस्याओं के अनुभव और ज्ञान की कमी के कारण बहुखंडीय कार्यप्रणाली का विकल्प भी प्रयोग में लाया जा सकता है। शैल बलविज्ञान के सरल नियमों का लाभ लेते हुए, इस आलेख में अति मोटे कोयला संस्तरों के अन्तिम निखनन हेतु इस नई परिकल्पना के विभिन्न स्वरूपों को प्रस्तुत किया गया है।

INTRODUCTION

Coal production target in India is being increased every year to meet increasing demand of energy. Underground winning of coal is a part clean coal technology and around 70% of the total reserve of the country is workable by underground mining but, at the moment, around 70% of the coal production is coming through opencast mining. Again, more than 60% of the total coal, workable by underground mining, belongs to thick seams[2]. Above mentioned scenario of the coal mining industry enhances the scope of under-ground extraction of thick coal seams. In recent past, a number of new mining methods have been introduced to improve productivity and safety. Some of the new methods to exploit the thick coal seams are indigenously developed while some are of foreign origin. Complicated nature of rock mass behaviour and difficult geo-mining conditions of the coal fields make it difficult to replace the conventional mining method by a new one. A review (Saha *et al.*, 1992) of different recent mining projects shows that in a number of cases introduction of a new mining method could not fulfil the techno-economic expectations. In fact, performance of a mining method for underground extraction of a thick coal seam is highly dependent on the geo-mining conditions of the site.

Also, most of the thick coal seams of India are developed with a 2.5 m average gallery height. The height of extraction can be increased by winning roof or floor coal to optimise coal recovery from the seam. Increased extraction height for better recovery from a thick coal seam severely affects the design and rating of roof support, movement of overlying roof strata, stability of pillars and, in fact, dilutes almost each and every safety norm of underground mining. These inherited geo-technical problems for underground exploitation of a thick coal seam becomes even worse under Indian geo-mining conditions mainly due to the presence of roof strata caveable with difficulty. The increase in the height

[1] *Superimposed development is a statutory requirement for contiguous sections. While, on the other hand, minimum 3m thickness of the parting is must between the workings of two close/contiguous sections/seams. Critically thick seam are those, which do not provide the required minimum 3m thickness of parting between the two contiguous sections to be developed for optimal exploitation of the seam.*

[2] *To be a thick seam in India, thickness of the coal bed should be more than 4.8m.*

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of extraction may not be suitable for the support system because the available conventional roof support systems are being generally designed for normal height of working. A high value of mining induced stresses in and around a depillaring face under a massive roof, generally, creates a threat of pillar overriding (Singh *et al.*, 1996). The chance of this threat further increases for depillaring of a thick coal seam as the height of extraction is inversely proportional to pillars/supports strength (Sheorey, 1993).

If a thick coal seam is developed along floor, taking the advantage of gravity, the roof coal band can easily be won by the well-known techniques like blasting gallery or cable bolting method during final extraction of the seam. But a very difficult geo-mining situation arises if the thick seam is developed along the roof horizon. Here seam thickness is an extremely delicate parameter, which generates two different conditions:

1. The seam, developed along the roof horizon, is thick enough to provide a 3m thick parting for the lower horizon working of the seam. Here the problem does not remain that difficult as the statutory requirement can be fulfilled.

2. The seam, developed along the roof horizon, is not thick enough to provide a 3m thick parting for the lower horizon working of the seam. Here the extraction of lower portion of the seam faces an extremely complex situation as the statutory requirement cannot be met.

Conventionally, the developed top section can be depillared first and then bottom section can be developed and depillared after settlement of the top section goaf. However, there is no standard time and process to ensure the settlement of the top section goaf. Stress concentration over the stooks, left inside the goaf of the top section, poses serous threat to the safety of the thin parting during bottom section working under thin and incompetent parting. Further cause of concern during bottom section working is accumulation of gas and heating of coal left in side the top section goaf.

CMRI has conceived an idea of safe, efficient, and economical depillaring by caving of whole seam in one lift. For this purpose, development of bottom section along floor can be done adopting cross development system. This paper presents different variants of cross development based final depillaring of a critically thick coal seam.

APPROACH AND APPREHENSIONS

It is to be noted here that superimposed development of contiguous sections of a seam is a statutory requirement. Even for this superimposed working of the contiguous sections, the parting thickness between the two sections should not be less than 3m in thickness. Underground experience of contiguous seams/sections working does not support conventional superimposed development of top and bottom sections if the parting is thin i.e. less than 3m in thickness. Reinforcement of the parting is through underpinning (Mandal et al., 2001) can be adopted if the paring is highly laminated and nearly 3m in thickness. However, the underpinning may also not ensure the stability if the parting is 1.5-2m only. Considering these facts, a new scheme of development (Fig. 1), called cross development, is recommended for bottom section development of a critically thick coal seam.

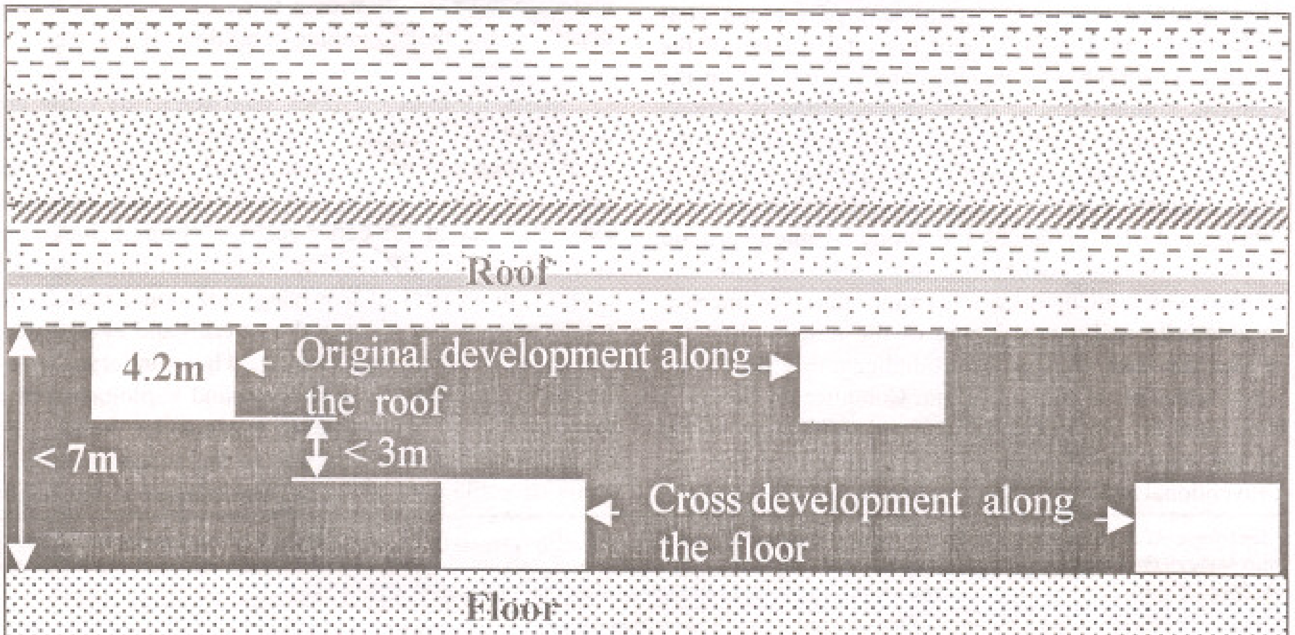

Fig. 1: Sectional view of cross development of a critically thick coal seam.

Once the seam is developed along the floor, taking the advantage of gravity, the roof coal band can easily be won by the well-known techniques like blasting gallery or cable bolting method during final extraction of the seam. Final extraction i.e. depillaring of a thick seam, developed only along floor, may not be very difficult but for the depillaring of a crossly developed seams/sections brings following three main apprehensions into consideration:

Eccentricity effect : Eccentricity is defined as the horizontal centre-to-centre distance between the two nearest roadways in top and bottom sections. The effect of eccentricity over the stability of roadways and pillars should be studied in depth.

Pillar load transfer : From stability point of view, superimposed development/working of contiguous seams/ sections provides most favourable situation for pillar load transfer. Staggering of the two workings is likely to disturb this ideal situation and so the stability of the underground structures is to be studied under different conditions of the depillaring operation.

Support of parting : The parting between top and bottom section galleries, at their crossing point, needs special attention as it is unlikely to be stable. This instability may also affect the ventilation scheme of the mine. Further, the prior anticipation of positions of top section galleries during drivage of development or slices galleries in bottom section is must for adoption of an effective roof support.

SITE DETAILS

The geo-mining conditions (Table 1) of No.1 seam at GDK-6B incline of RG-I area, SCCL seams to be a suitable site for the cross development based depillaring. Depillaring of the crossly developed seam in one lift with caving will be a new mining practice and is likely to bring a number of parameters into consideration and may not be appropriate to be tried at the first stage of the experiment. Therefore, at the first stage of the experiment, the final depillaring of the seam has been planned in two sections with stowing. This approach will also be suitable to improve the quality of coal as the shale band of the seam (Fig. 2) can easily be discarded.

Table 1: Geo-mining conditions of No. 1 seam at GDK-6B incline.

Sl. No.	Parameter	Value
1	Reserve	5.2 MT extractable
2	Thickness	6.1m
3	Pillar size	20m x 20m & 35m x 35 m (centre to centre)
4	Gallery width & height	4.2 m & 2.0 m
5	Thickness of floor coal	3.8 to 4.1 m
6	Cover thickness	25 to 250 m

NUMERICAL MODELING

In order to assess the behaviour of underground structures and the resulted parting under the influence of superimposed and cross developments, the geo-mining conditions of the site was simulated in laboratory by numerical modeling. A two dimensional finite difference code (FLAC) is used for this purpose. The rock mass properties used for modeling are given in Table 2.

In situ stresses were simulated according to following equations:

$$S_v = 0.025\,H \quad \text{MPa}$$
$$\&\ S_H = S_h = 2.0 + 0.01H \quad \text{MPa}$$

Where, H = Depth cover in meter,
S_v = Vertical in-situ stress,
S_h = Minor horizontal in-situ stress &
S_H = Major horizontal in-situ stress

In order to assess the stability of natural supports and the exposed span for superimposed and staggered developments, safety factors are calculated using CMRI failure criterion as given below:

$$\sigma_1 = \sigma_3 (1 + \frac{\sigma_3}{\sigma_{tm}})^{b_m}$$

Thickness m	Formation	UHV kCal/kg
0.8	Coal	3546
0.7	Coal	4879
0.6	Coal	4629
0.3	Clay	-
0.4	Shale	-
0.8	Coal	3553
2.5	Coal	3612

Figure 2: A typical result of band distribution study of the coal seam.

$$\sigma_{cm} = \sigma_c e^{(\frac{RMR-100}{20})}$$

$$\sigma_{tm} = \sigma_t e^{\frac{(RMR-100)}{27}}$$

$$b_m = b^{\frac{RMR}{100}}$$

Where, σ_1 = Tri-axial strength of rock mass, MPa, σ_3 = Confining stress, MPa, σ_c = Compressive strength of intact rock, MPa, σ_t = Tensile strength of intact rock, MPa, b = exponent in failure criteria, which controls the curvature of triaxial curve, σ_{cm} = Compressive strength of rock mass, MPa, σ_{tm} = Tensile strength of rock mass, MPa and RMR = Biniewiski Rock Mass Rating.

The factor of safety is defined as

$$SF = \frac{\sigma_1 - \sigma_{3i}}{\sigma_{1i} - \sigma_{3i}} \qquad for\ \sigma_3 < \sigma_t$$

$$SF = \frac{\sigma_t}{\sigma_3} \qquad for\ \sigma_3 > \sigma_t$$

Where, σ_{1i} = Induced major principle stress, MPa, σ_{3i} = Induced minor principle stress MPa.

Using the above failure criterion and the results of numerical modeling, safety factor contours of partings for superimposed and staggered developments of the bottom section of No. 1 seam at GDK-6B incline are plotted in Figs. 3, 4 and 5. A three dimensional modeling for such a study (CMRI Report 2001) also reported similar type of findings for the working of a critically thick coal seam.

Table 2 : Material Properties as used in numerical modeling

Material	Young's Modulus (MPa)	Poisson's ratio	Bulk Modulus (MPa)	Shear Modulus (MPa)	Density (Kg/m³)
Sand stone	6000	0.25	4000	2400	2548
Shale	5000	0.25	3330	2000	2200
Coal	2000	0.25	1330	800	1400
Caved Rock	200	0.1	83	91	2000

EXTRACTION WITH STOWING

On the basis of experience, conventional superimposed development of top and bottom sections is not possible under the existing geo-mining conditions. Incompetent parting is likely to create roof instability

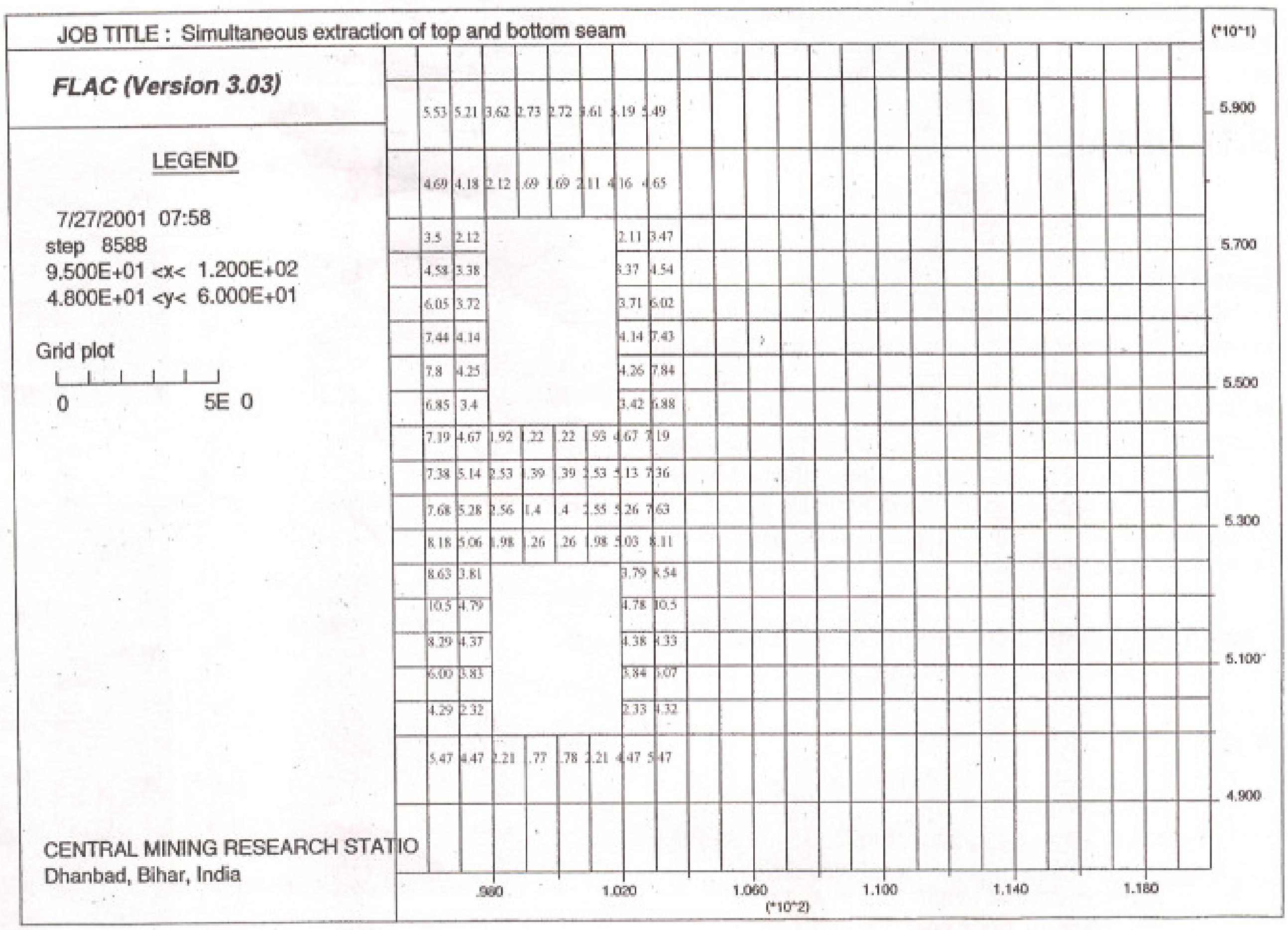

Figure 3 : Safety factor of parting for superimposed developments

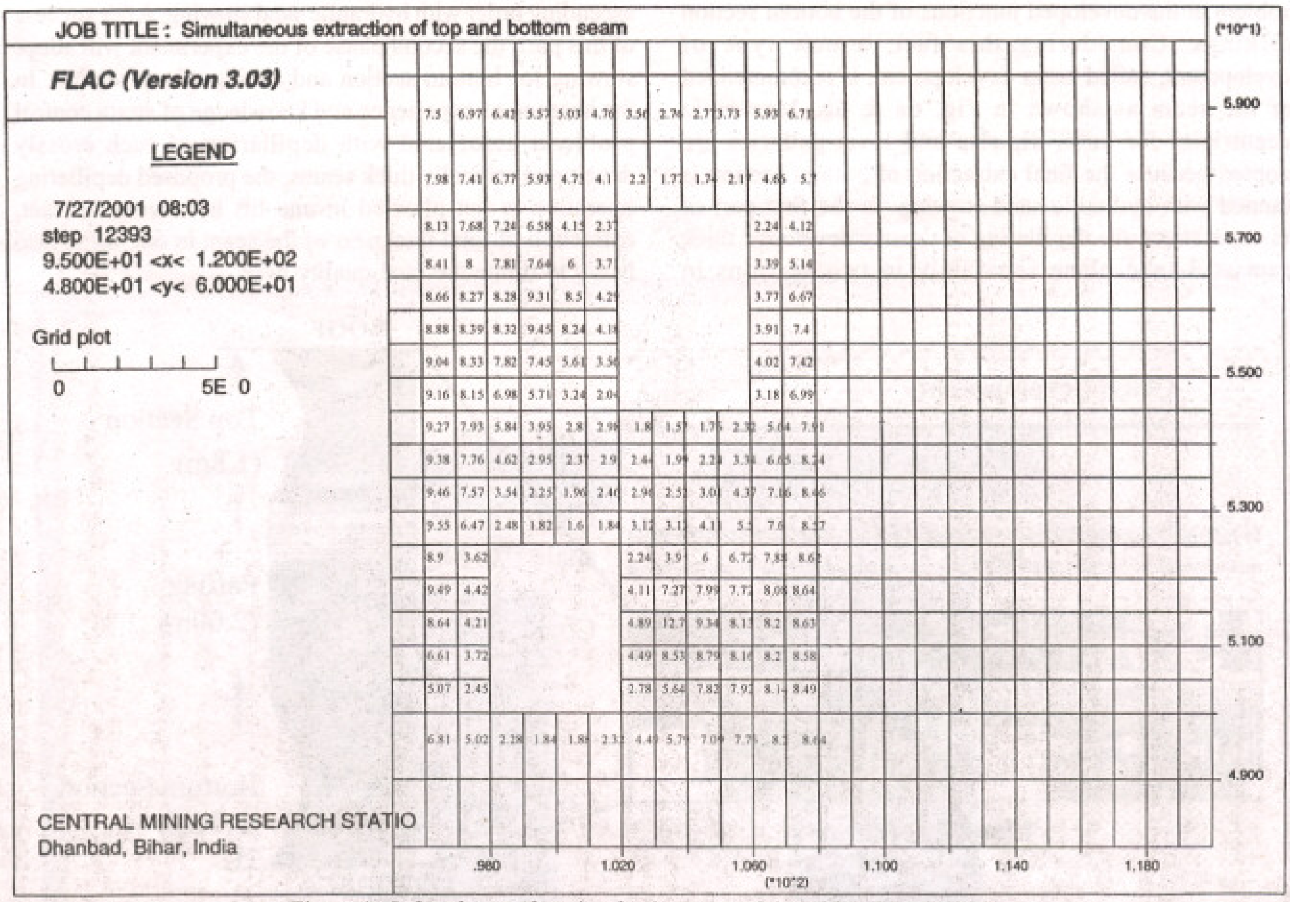

Figure 4 : Safety factor of parting for 4 m eccentricity of developed pillars.

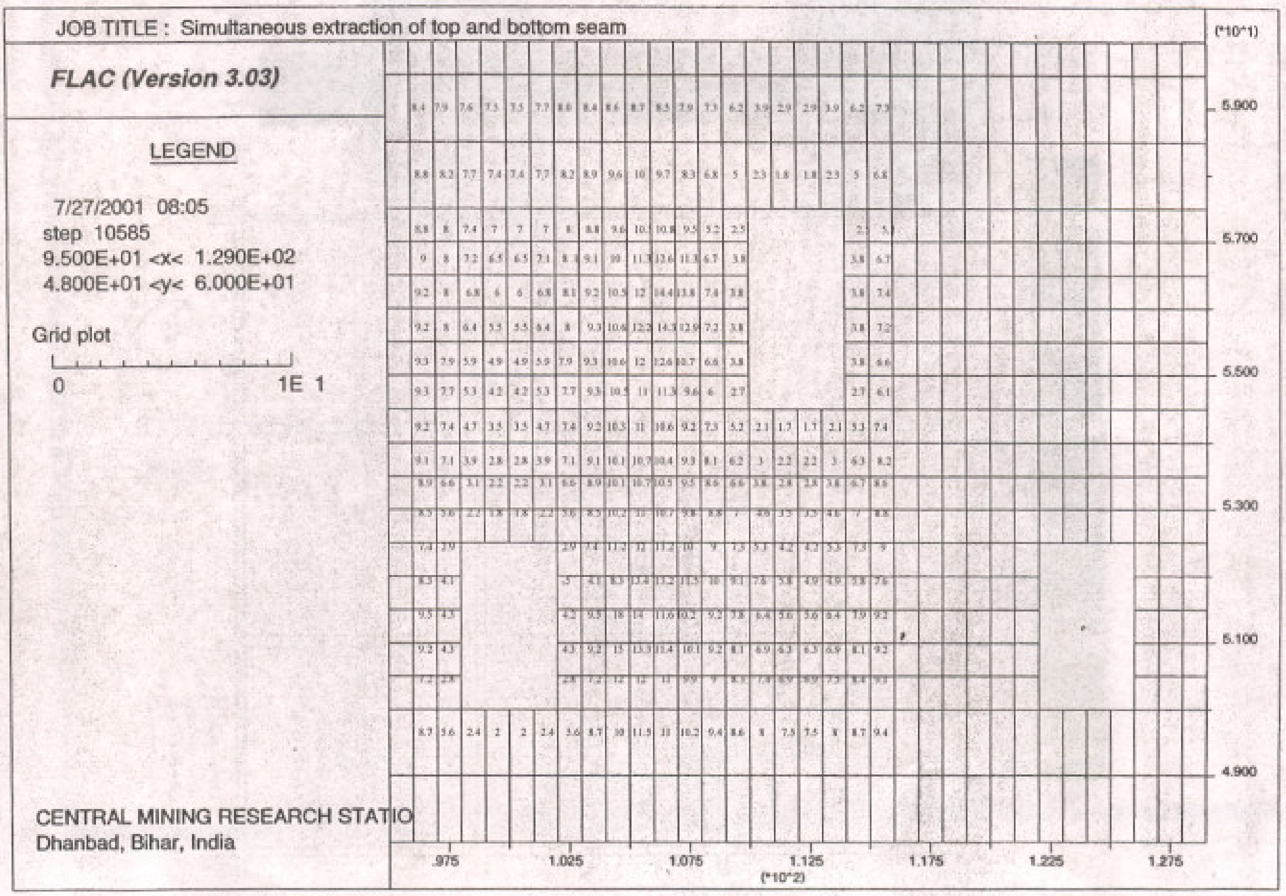

Figure 5 : Safety factor of parting for 12 m eccentricity (middle of the pillar) for development.

problem at the developed junctions of the bottom section workings. Considering this fact, a new type of development, called cross development, is recommended for the seam as shown in Fig. 6a & 6b. Maximum eccentricity for both, dip-rise and level galleries are adopted because the final extraction of bottom section is planned with hydraulic sand stowing. In the first part of the experiment, the depillaring of crossly developed thick seam will take place separately in two sections in ascending order with hydraulic sand stowing. After success of this part, the second phase of the experiment will adopt stowing for bottom section and caving of top section. In the absence of experience and knowledge of strata control problems associated with depillaring of such crossly developed critically thick seams, the proposed depillaring operation is not planned in one lift by caving. In fact, extraction of total thickness of the seam in one lift is also likely to dilute the coal quality here.

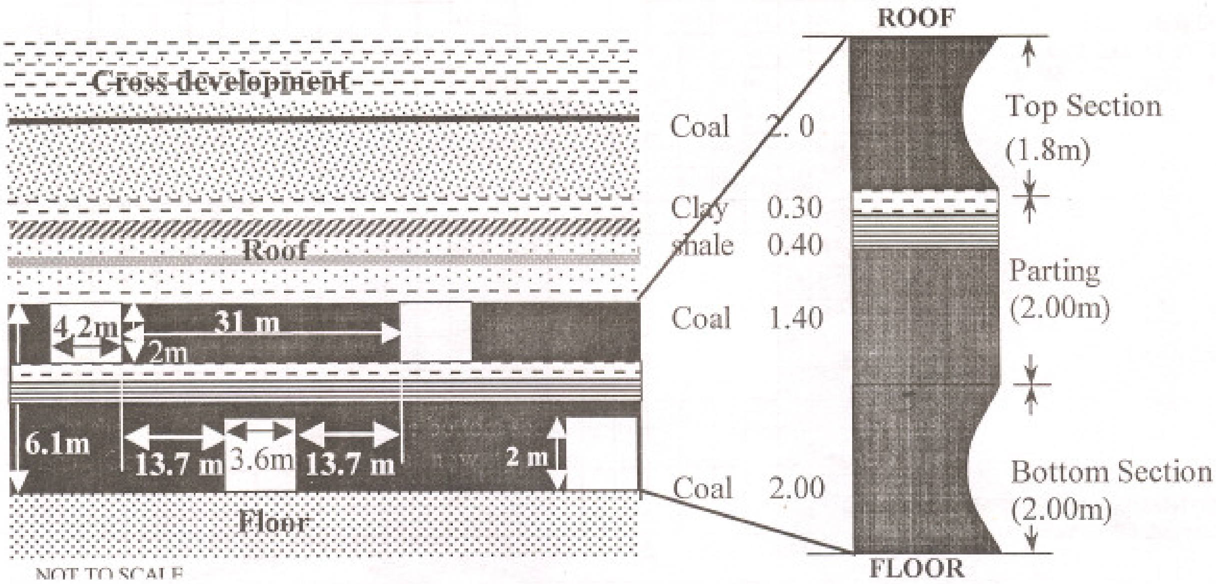

Fig. 6a

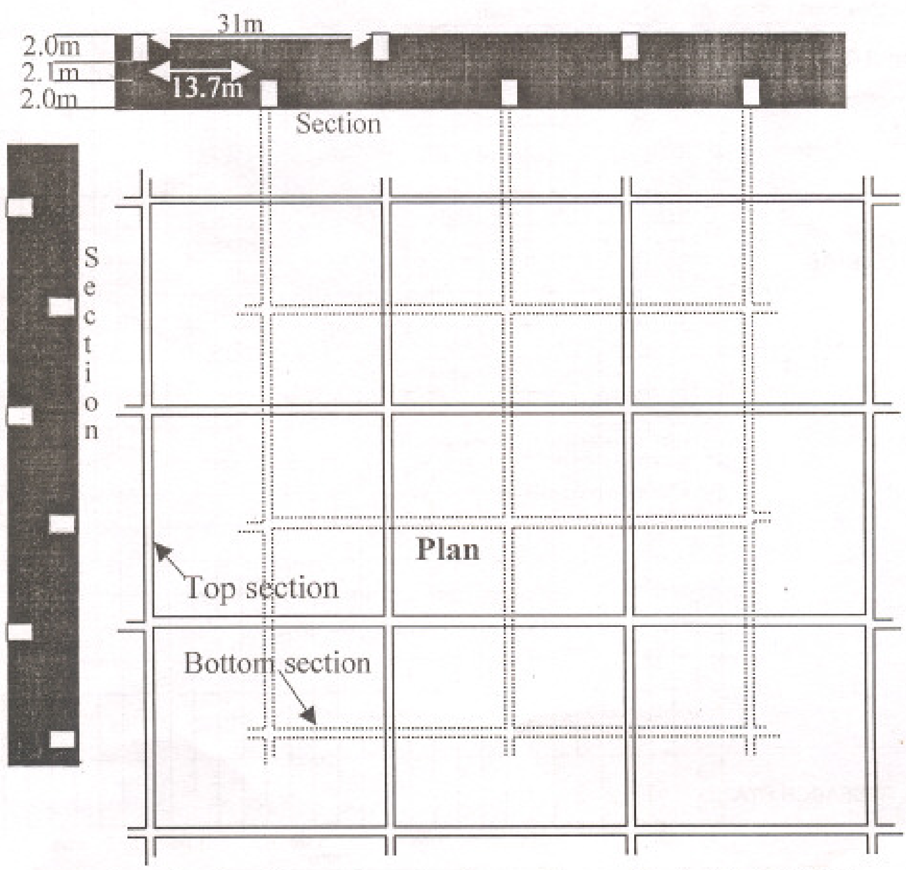

Fig. 6: Plan and sectional views of cross development for seam No. 1 of GDK-6B incline.

SUPPORT SYSTEM

Considering the situation of cross development of bottom section; the rock load for bottom section development was calculated as per CMRI approach. Taking the anchorage strength of a full column grouted roof bolt of 2m length equal to 6 tons, the required support system for bottom section development is shown in Fig. 7. In view of the thin parting of around 2 m thickness only, the modeling suggested application of goal post support system as detailed in Fig. 7. Slicing of the bottom section pillars should be done first in conjunction with hydraulic sand stowing. However, there are a number of occasions when the bottom section working is likely to be directly below the workings of the top section. To apply effective support system for the bottom section workings, there is a practical requirement of detection of top section gallery position in bottom section working. This can be done through underpinning of top section floor in advance with relatively longer inclined bolts along both sides of the existing galleries. Working below top section gallery should be done with goal post support system, which can be withdrawn during stowing of the goaf. Final extraction of top section pillars should commence in conventional manner with hydraulic sand stowing after complete packing of the bottom section voids.

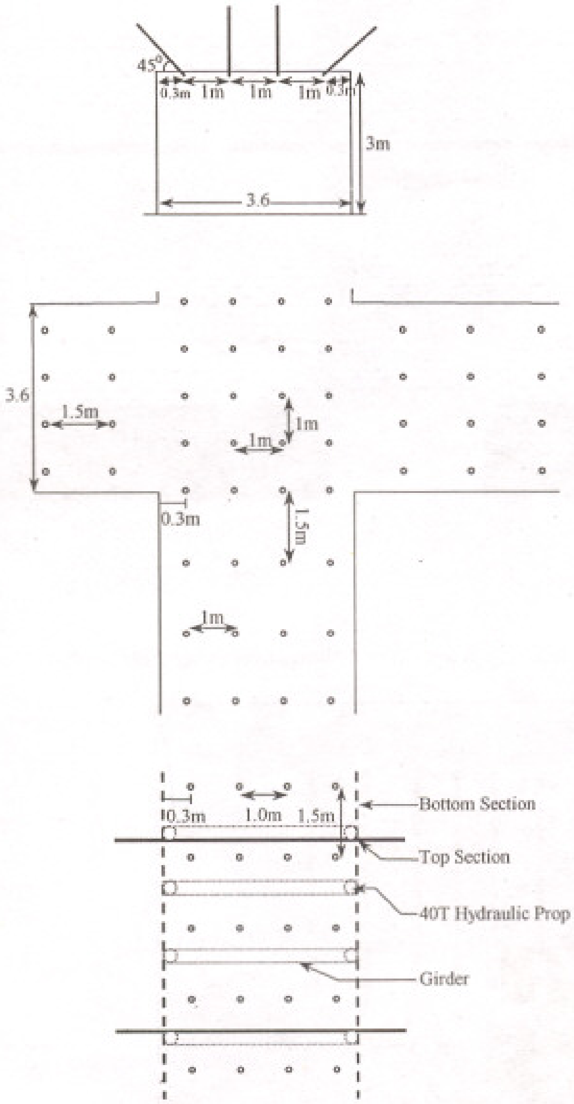

Figure 7: Support System for development of bottom section

EXTRACTION WITH CAVING

For the geo-mining conditions of No. 1 seam at GDK-6B incline, stowing of bottom section and caving of top section may be the final method of working for the seam to keep the quality of coal intact. However, it is always preferred to win the entire thickness of a crossly developed thick coal seam in one lift. For this purpose, the proposed methodology is divided into two parts according to the cover of the seam.

Deeper portion of the seam has got wider pillars (31x31m) which provides some space to play with the eccentricity of the bottom section roadways. As per the results of numerical modeling, maximum eccentricity provides the best stability for cross development. But, keeping final splitting and slicing into consideration, the new pattern of development and manner of depillaring are shown in Fig. 8. Here the split galleries of bottom section during final extraction will have the same maximum possible eccentricity as that of the level development galleries. Adopting conventional splitting and slicing of normal height along floor, the roof coal can be won during retreat. The roof and floor of the top section working has to be bolted before bottom section development. Goalpost support systems are to be adopted for the roadways/slices of bottom section below the top section galleries. Rest of the roadways/slices of the bottom section is to be supported by cable bolts, which will work as high roof support to win the roof coal during retreat.

Coal pillars at shallow cover are smaller in size so the change in eccentricity of the cross development has got limited scope. However, pillar spalling does not occur at shallow cover as the pillar experiences less vertical stress. Taking advantage of this simple fact, the floor coal of the existing galleries can be won after roof and side bolting (Fig. 9) of the pillars. Adopting cable bolting based conventional splitting and slicing of normal height along floor; the roof coal can be won during retreat using cable bolt (Fig. 10) as high roof support. Based on simple rock mechanics principles, the idea of using grouted steel rope under tension to support an overlying coal band, as well as, a high roof and to improve safe span of the overhanging beam/cantilever near the goaf edge of semi-mechanised depillaring of a developed thick coal seam (standing on pillars) provided excellent results (Singh *et al.*, 2001) during the field trial and discarded haulage ropes were well utilised. Reinforcement of the immediate coal roof band and the overlying roof well in advance of the actual depillaring operation are going to play an important role in extraction of thick and developed coal seams in the country.

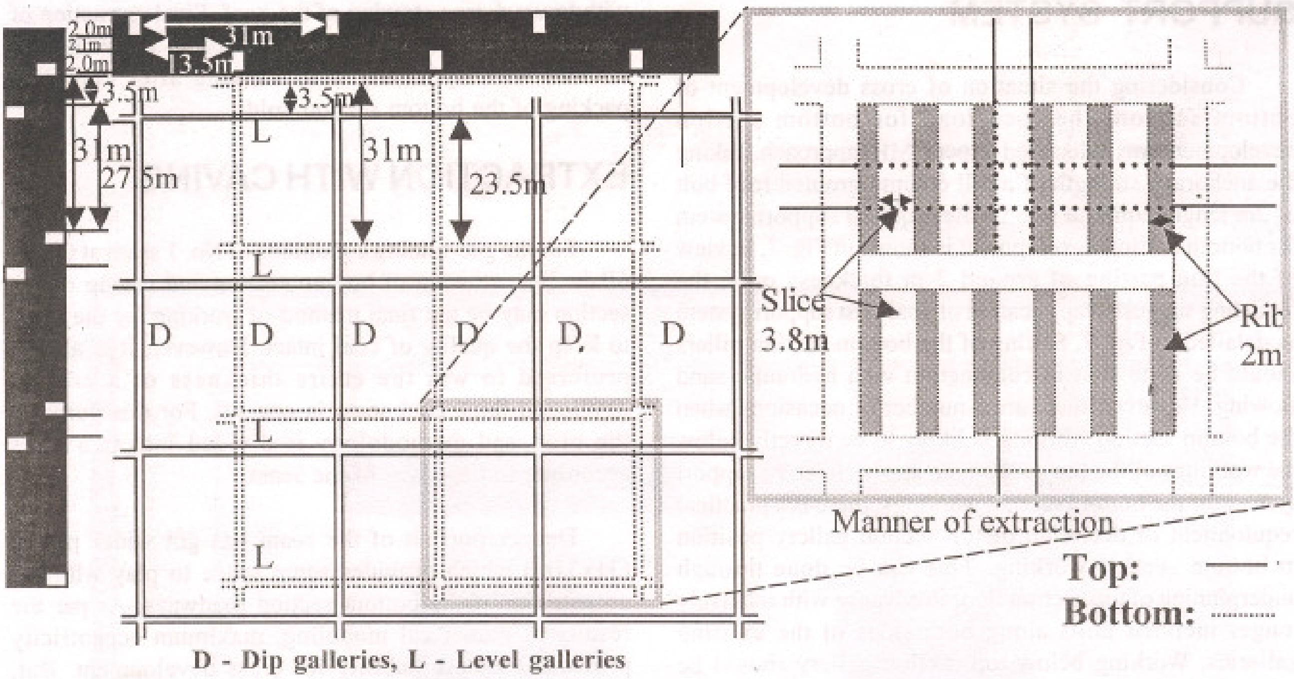

Fig.8: Depillaring plan of crossly the developed seam.

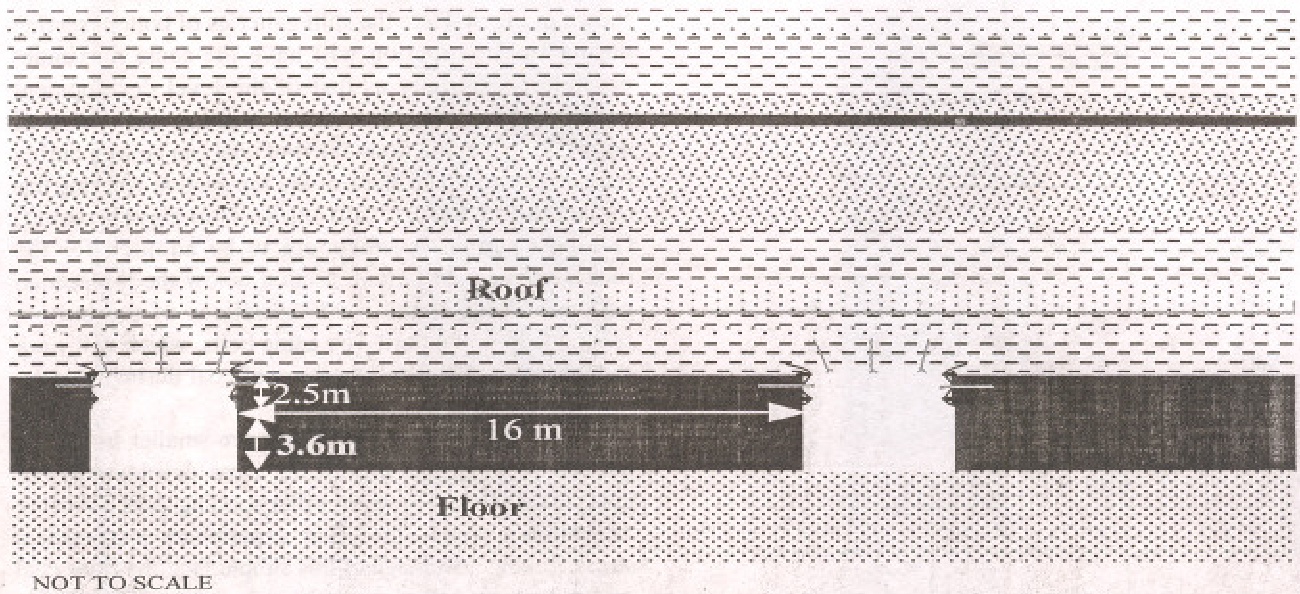

Fig. 9: winning of floor coal after side stitching and roof bolting for depillaring in one lift at shallow cover using cable bolting.

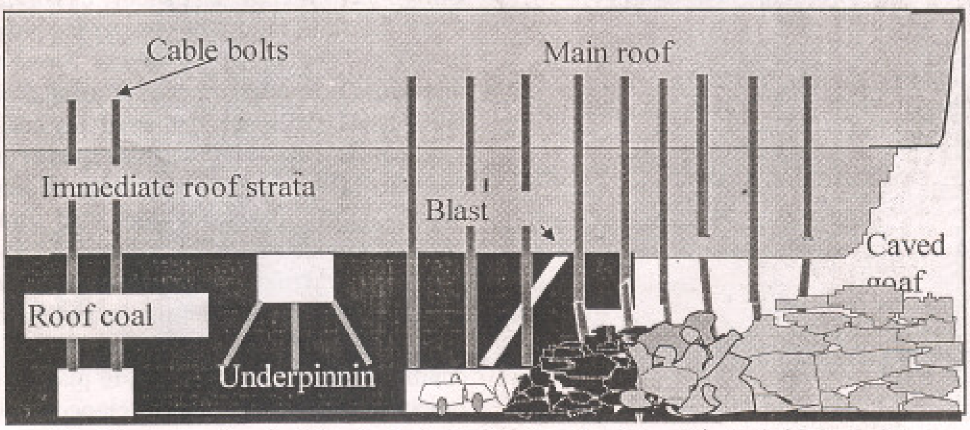

Fig. 10: Application of cable bolts for single lift extraction of the critically thick coal seam.

CONCLUSIONS

Depth of the seam is a considerable parameter for selection of a mining method for final extraction of a critically thick coal seam, developed along roof horizon. The idea of cross development based depillaring of a critically thick coal seam at higher cover (developed on pillars along the roof) consists a number of options for safe and optimal underground extraction of coal locked under difficult geo-mining conditions. After success of the initial trails of multi-section workings with hydraulic sand stowing, the technology is likely to mature with underground extraction of total seam thickness in one lift with caving. Although laboratory results are supporting the approach, actual field trial of this mining method will be able to establish the efficacy of this concept. Adoption of suitable rock mass reinforcement method and advantage of low vertical stress at shallow cover may help us in extracting the whole thickness of the seam in one lift.

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