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STRATA BEHAVIOUR INVESTIGATIONS OF INDIA'S FIRST DEPILLARING FACE WITH CONTINUOUS MINER AND SHUTTLE CAR

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भारत में खुली खदानों की उच्च उत्पादकता के समक्ष भूमिगत कोयला खनन अपने अस्तित्व को बचाने में संघर्षरत है। सरकारी नीतियां भी इस प्रतियोगिता को कठिन बना रही हैं। वास्तव में भूमिगत खनन बेहतर कोयला उपलब्ध कराता है, भू-सतह पर बेहतर पर्यावरण देता है और गहरे कोयला भंडारों के खनन का एकमात्र विकल्प है। भारतीय कोयला उद्योग परम्परागत डिपिलरिंग तकनीक से जुड़ी निम्न उत्पादकता की समस्या से निपटने के लिए उपयुक्त तकनीक का मुँह जोह रहा है। वस्तुत: आज बहुत बड़ी संख्या में कोयला संस्तर सुरक्षित एवं लाभप्रद अन्तिम निकासी के लिए पिलर में उपयुक्त तकनीक की प्रतीक्षा में पड़े हैं। मे॰ साउथ ईस्टर्न कोलफील्ड्स लि॰ की अंजन खान में भारत के प्रथम कॉन्टीन्युअस माइनर डिपिलरिंग पैनल ने भूमिगत कोयला खनन की निम्न उत्पादकता की समस्या से निपटने की दिशा दिखायी है। इस आलेख में 'कॉन्टीन्युअस माइनर एवं शटल कार के साथ रूफ बोल्ट का प्रयोग' सफलता पूर्वक कर बिना स्ट्राटा नियंत्रण की किसी समस्या के साथ 12 मीट्रिक टन प्रति मानवपारी की उत्पादकता प्राप्त करने का विस्तार से वर्णन किया गया है।

INTRODUCTION

Underground mining in India has slipped its place of prominence to opencast mining mainly due to its low productivity. But, production of coal from opencast mining comes at the cost of quality dilution, large scale land degradation and adverse affects on surrounding environment. Underground mining provides better quality of coal, protects surface environment and the only option left for extraction of deeper deposits. The coal reserves, suitable for extraction by opencast mining are decreasing day by day.

Considering favourable points of underground mining, large number of coal seams has extensively been developed by formation of pillars to meet the increasing demand for coal in India. This is found to be a simple and safe method of coal production from underground mines. The process of pillar formation also received favourable situation due to presence of the competent coal seam and surrounding rock mass. Indian Coal Mines Regulations, 1957 (CMR, 2000) is also quite liberal for pillar formation. This strategy of coal production found suitable for the Indian coal mining industry because of low capital investment and involvement of trivial technical expertise. Now, industry is looking towards the huge amount of coal locked-up in the pillars. Underground coal mining in India is facing serious techno-economical challenge during depillaring of the developed coal seams. Conventional depillaring frequently encounters strata control problem and the productivity remains quite low. In fact, generally, the strata control problem and poor rate of production are also interlinked (Singh and Singh, 1990). The productivity competition is now global due the changing policies of the government. Underground coal pillar extraction with competitive productivity and safety is of strategic importance for the coal mining industry of the country. The main bottleneck in this endeavor has been the technological vacuum for better exploitation of seams by underground mining methods.

Successful application of Continuous Miner and Shuttle car along with roof bolting technology for mass production at Anjan Hill Mine has, probably, conveyed a great message to counter the productivity problem of depillaring. Anjan Hill mine of M/s South Eastern Coalfields Ltd. (SECL) witnessed country's first fully mechanized depillaring face in technical collaboration with Joy Mining Machinery (JOY), and Rock Mechanics Technology (RMT) U.K. Here, only roof bolts were used to support all working areas including breaker line support at the goaf edges during depillaring of the panel. Central Mining Research Institute (CMRI) was entrusted to conduct performance evaluation and strata behaviour study during field trail of the Continuous Miner technology. This study in the first

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panel 'C' of the mine showed outstanding techno-economical performance (Leeming, 2003) of the technology. Statistical and technical performance evaluation of the application of roof bolts as breaker line support was observed to be a great success for the geo-mining conditions of the depillaring panel of the Anjan Hill Mine. However, the load distribution study along the bolts of different rows of the breaker line support in panel 'C' revealed that the three rows of bolts for the breaker line support between slices might be reduced to two rows only. Later, this modified version of the breaker line was successfully implemented to arrest goaf encroachment during roof fall in panel 'B' of the mine. This paper presents the case study of the country's first continuous miner based depillaring panel along with the results of strata control investigation, conducted to visualise the in situ performance of the technology.

GEO-MINING CONDITIONS

Zero seam of 5.33 m average thickness at Anjan Hill mine, SECL was developed in a single section along floor. Development was made leaving 0.6 to 1.0 m thick coal band along the roof. Average size of the developed pillars was 33 x 33 m (centre to centre) and average gallery width was 4.8 m. Total reserve of Zero seam (thickness ranges from 3.0 to 5.33 m) was 1.1 million tones in the leasehold area of the mine. No extractable overlying seam was present over the zero seam. Panel 'C' (Fig.1) of the mine was selected for application of the technology. Coal seams of the basin are of Barakar stage under Lower Gondwana period, which has gained 435 m thickness in this coalfield. The formation intercepted in B. H. No. CHA-5 and CHA-6 (Fig. 2) shows a number of coal horizons, starting from surface and the Zero seam (Bottom) touched at 69 m depth in B.H. No. CHA-5

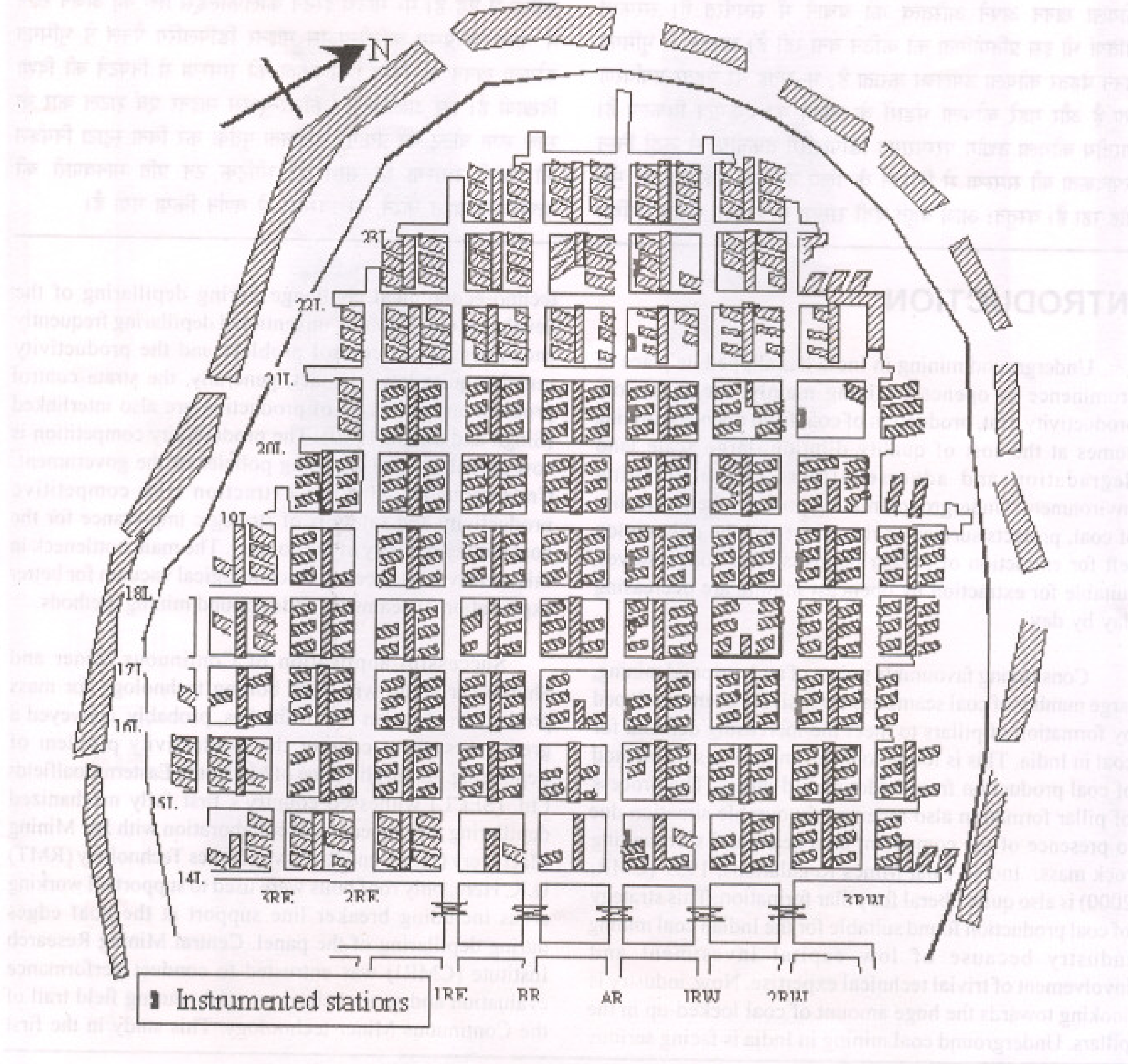

Fig.1: Plan showing the location of instruments and manner of slicing in panel 'C'

and 49.03 m in B.H. No. CHA-6. The panel consisted 70 pillars. Depillaring of the panel started on 26/02/03 and sealed on 20/07/03 after final extraction of the pillars. Table 1 gives dimensional details of workings in the panel.

Table 1: Dimensional details of workings in panel 'C'

Parameter	Description
Size of pillar	33 x 33 m (centre to centre)
Gallery width	4.8 m
Seam thickness (average)	5.33 m
Development height	4.5 m
Extraction height	4.5 m
Width of split gallery	6.6 m
Width of slice (maximum)	6.6 m
Depth cover	120 m (Max.) and 52 m (Min.)
Gradient	1 in 30
Incubation Period	6 months

METHOD OF MINING

Both, Continuous Miner and conventional drilling and blasting were used for development of the seam on pillars through formation of 4.5 m wide and 3 m height galleries along floor. A sectional view of the development of the seam is shown in Fig. 3. Final extraction of the pillars was made by pocket-and fender method (Leeming, 2003) using remotely operated Continuous Miner and Shuttle car combination. In this method the developed pillars were split into two halves by a dip and rise split and each half pillar was extracted by incline slices as described below.

A pillar was split into two stooks by driving 6.6 m wide (later on, a decision was taken to reduce the width of split gallery to 6 m only) and 4.5 m height gallery leaving at least 0.6 m coal against the immediate shale roof. The half pillar was extracted by driving slices at an angle of about 60° with respect to the center of the split gallery. Width and height of slices were kept nearly 6.6 m and 4.5 m (leaving coal of at least 0.6 m against the shale roof) respectively against a coal rib more than 2 m thickness in between the

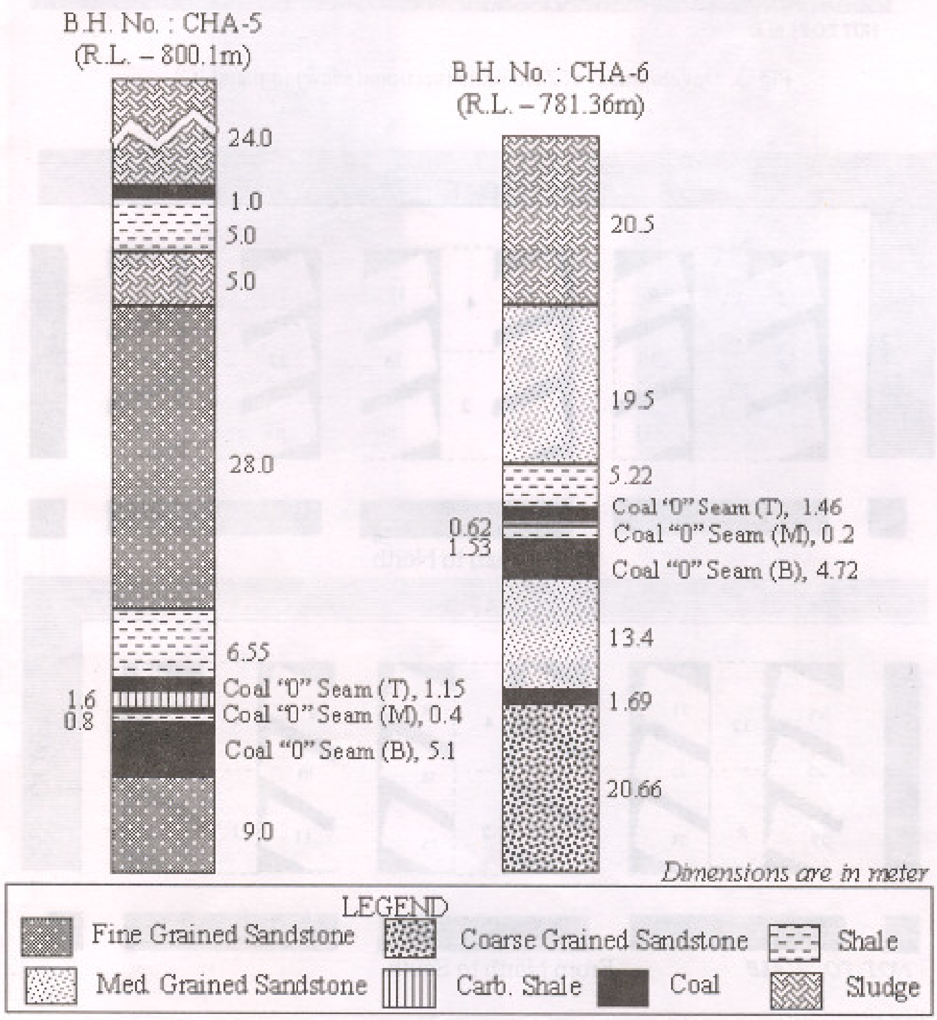

Fig. 2: Strata formations at Anjan Hill mine, Chirimiri Area

slices. These ribs were judiciously reduced during retreat. The first slice of the half pillar started at 5 m distance from the corner of the pillar. However, this distance was increased up to 7 m in case of an overhanging goaf. Width of a slice was restricted to 6.6 m; some times 3.3 m only and at few occasions it was left intact in case of observation / anticipation of instability of the slice. The maximum cut off distance in split and slice was kept below 14 and 10 m respectively. At any moment of time, only two pillars were attacked; one under splitting and another under slicing, except at the time of commencement of extraction in a separate row of pillars where splitting was extended to maximum two pillars. The line of extraction remained straight and not diagonal. Extraction of pillars started from the dip and in bye and proceeded systematically to the rise and out bye side. In this panel, initially the cutting sequence was started from South to North up to three rows of pillars but later on the cutting sequence was changed from North to South direction (Fig. 4) for rest part of the panel.

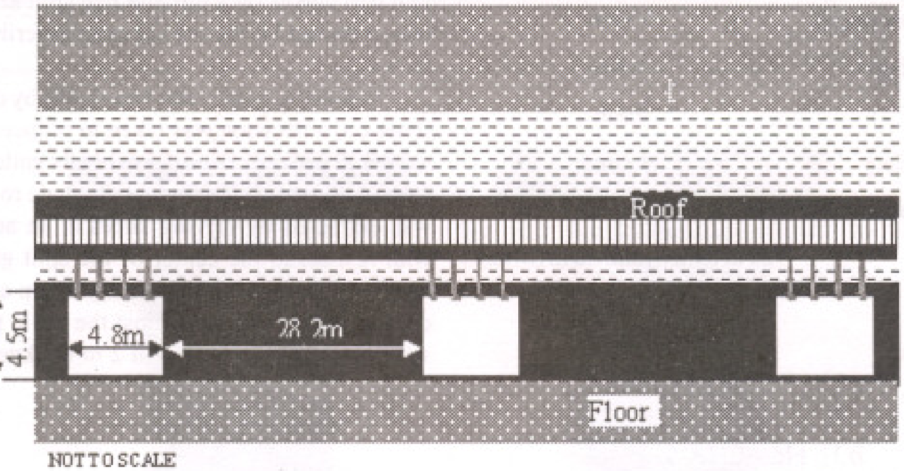

Fig. 3: Development of Zero seam (sectional view) in panel 'C'

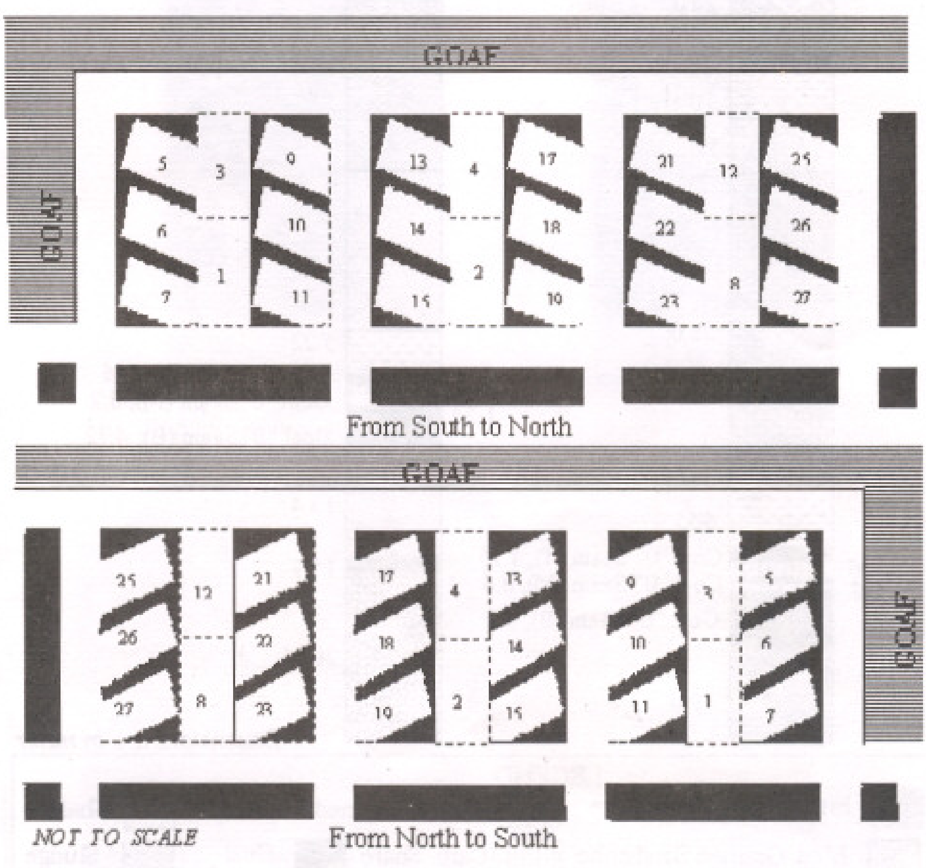

Fig. 4: Two different cutting sequences adopted for extraction of pillars from panel 'C'

SUPPORT SYSTEM

Only roof bolts were used to support galleries, working places and goaf edges. The original galleries were supported by four rows of non-retractable roof bolts consisted of 22 mm cold threaded steel, 2.4 m long roof bolts along with 150 mm x 150 mm x 1.25 mm bearing plate. The roof bolts were grouted in 27 mm diameter of hole with the help of resin capsules keeping an annular spacing of 5 mm only. In each hole, one quick setting resin capsule, 450 mm in length and one slow setting resin capsule, 800 mm in length and 23-24 mm diameter were used for the grouting. The distance between the rows of the roof bolts as well as between the roof bolts in the same row was 1.0 m. At disturbed places, the galleries were supported by roof bolts along with W-strap. All the goaf edges were supported with three rows of non-retractable roof bolts at 0.8 m interval in between two bolts as well as between two rows of the bolts and between last bolt and side of the pillar. In a split gallery, the side bolts were 0.9 m away from the edge of pillars. The length of bolts installed in split/original galleries as breaker line supports[1] was 1.8 m. Two wooden indicator props were erected near the goaf edge on the rib side to visualize the strata movement. The position of breaker line supports at the goaf edge during depillaring in panel 'C' is shown in Fig. 5. The observed condition of the galleries/splits, made by the Continuous Miner, was quite smooth due to, relatively, gentle action of the machine for breaking the coal. Some undulation in the exposed surface was observed only near the slip planes in the coal mass. All the split galleries were supported by three rows of non-retractable roof bolts of 1.8 m length (Fig. 6). The distance between the two adjacent rows of roof bolts and that between two adjacent bolts in a row was 1.65 m. Slices of the working remained unsupported (Lind, 2002a) mainly due to their short life and remotely controlled coal cutting and lifting system.

[1] *The breaker line support is a triple row of roof bolts to support the goaf edge, which formed a breaker line between the advancing goaf and the current working place.*

Immediate roof always provided enough time to extract the pillars and approach to the next pillars except a few cases, where the stooks/slices under extraction were not taken (Fig.1) mainly due to local geological disturbances like slip, joints etc. The first local fall, covering an area of 1617 m^2, took place after creation of the void area of 3000 m^2. The first major fall took place on 17/03/03 covering 2336 m^2 area, when total exposed area was 9919 m^2.

STRATA CONTROL INVESTIGATIONS

The depillaring panel was equipped with a number of instruments to monitor the mining induced stress (vertical), load distribution over roof bolts, bed separation and closure between roof and floor along with goaf settlement. Some of these instruments were installed by RMT (UK) while others were installed and monitored by CMRI (CMRI Report, 2003). In fact, CMRI studied stress redistribution and roof to floor convergence by vibrating wire stress meters and remote convergence indicators respectively using data logger, a microprocessor based automatic monitoring system. These instruments were installed after a complete analysis of the geo-mining conditions of the panel and aimed to generate an effective data set for the evaluation of performance of different underground structures during the mining.

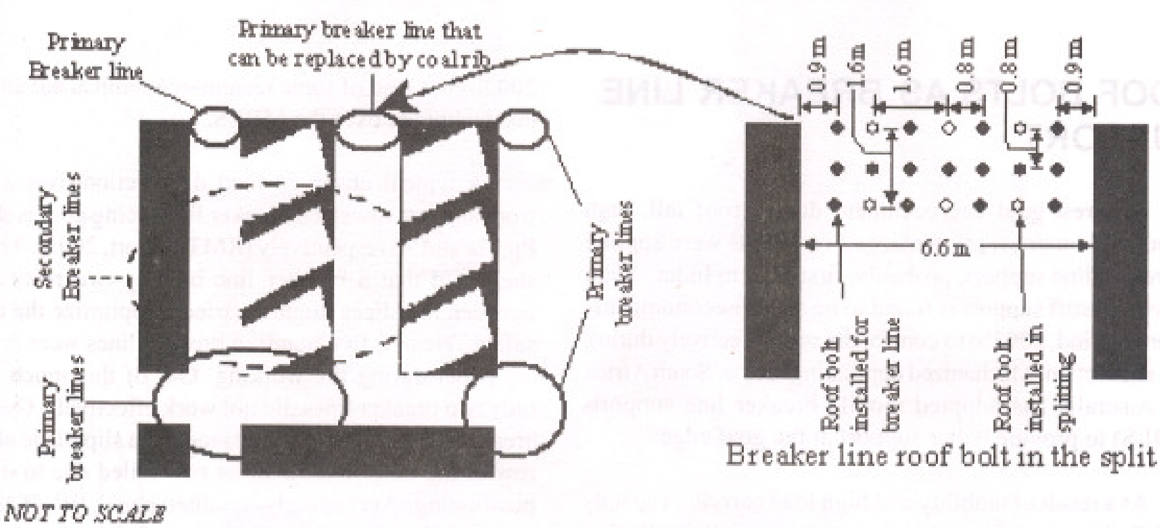

Fig. 5: Breaker line placement with respect to slice position

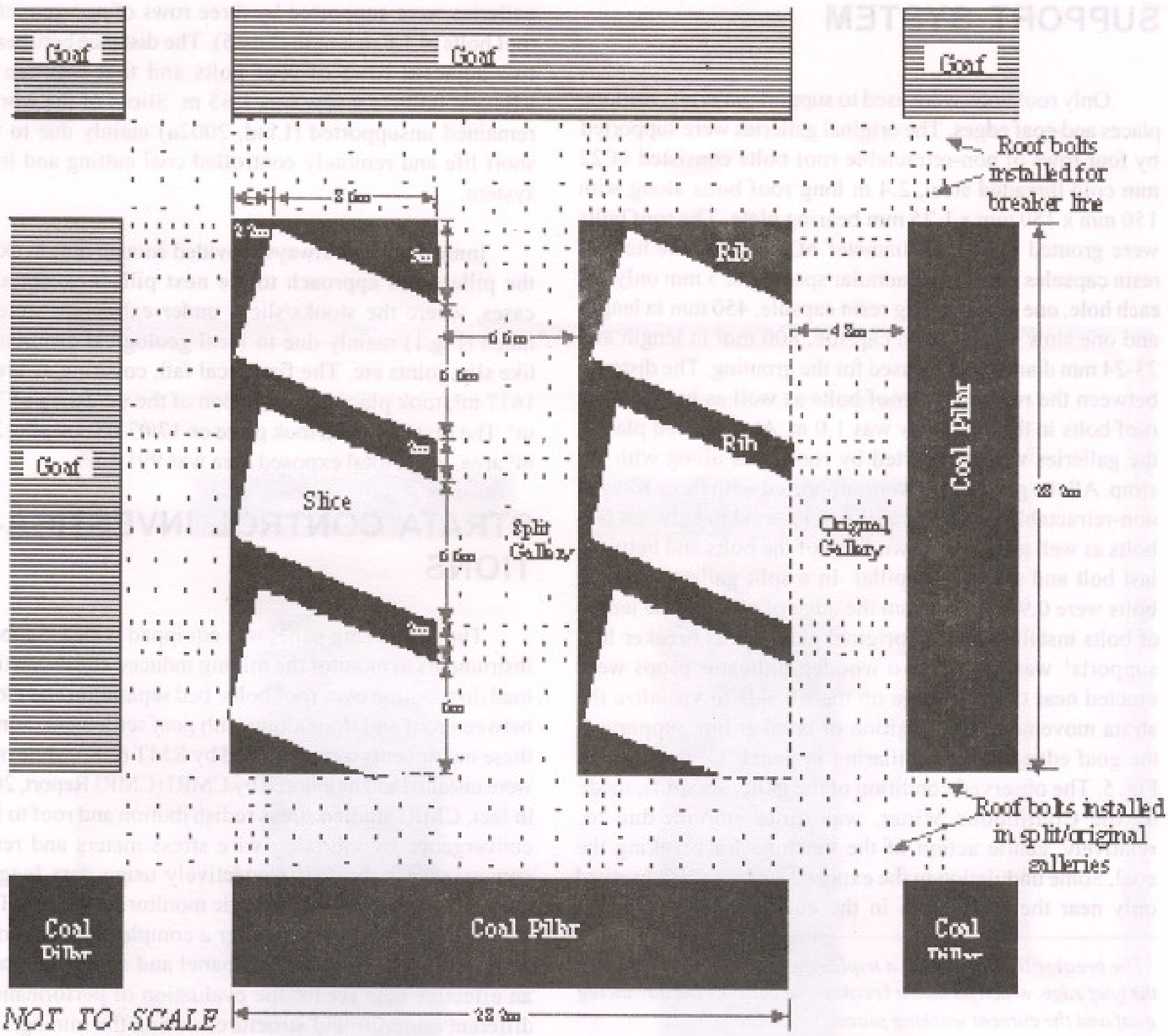

Fig. 6: Systematic support during depillaring by continuous miner and shuttle car combination

ROOF BOLTS AS BREAKER LINE SUPPORT

To arrest goaf encroachment during roof fall, high capacity (24 tonnes) pre-tensioned roof bolts were applied as breaker line support, probably, first time in India. Such active and stiff support is found to be techno-economically superior (Lind, 2002b) to control the roof effectively during final excavation. Mechanized depillaring face of South Africa and Australia has adopted mobile breaker line supports (MBLS) to provide better support at the goaf edge.

As a result of mobility and high load carrying capacity MBLS, they are safer and increases the overall production cycle of the mining. However, the application of roof bolts as breaker line support is successful and consistent (Lind, 2002b) because of some techno-economical advantages of this technique over the MBLS.

A typical observed load distribution over a bolt of front and last rows of a breaker line facing goaf is shown in Fig. 7a and 7b respectively (RMT Report, 2003). This study suggested that a breaker line of only two rows of bolts between the slices might be tried to optimize the cost and safety. Nearly, five hundred breaker lines were erected in the panel during the working. Out of this much number only two breaker lines did not work effectively. One row of breaker line failed due to presence of a slip plane along the row of the bolts and the other row failed due to its wrong positioning. Accordingly, another panel 'B' of the mine successfully adopted (CMRI Report, 2004) a breaker line of only two rows of bolts between the slices without any strata control problem.

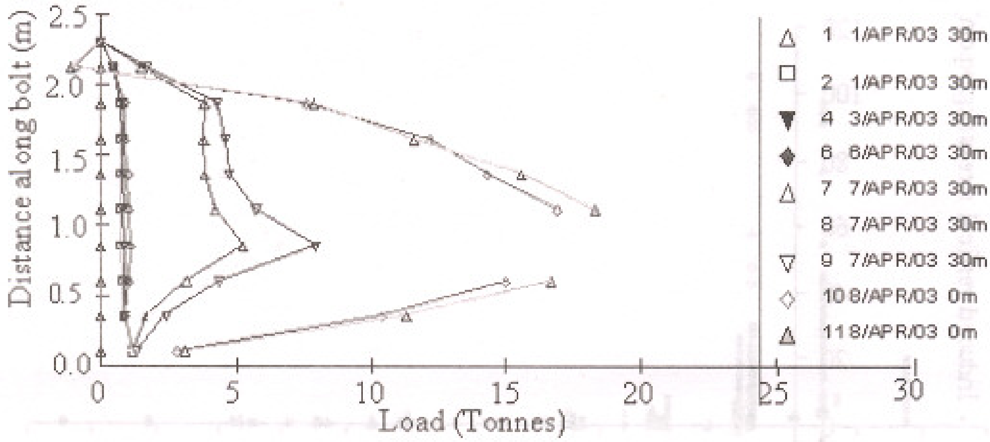

Fig. 7a: Development of axial load across a roof bolt of front row (goaf side) of a breaker line at different stages of a depillaring in panel 'C'

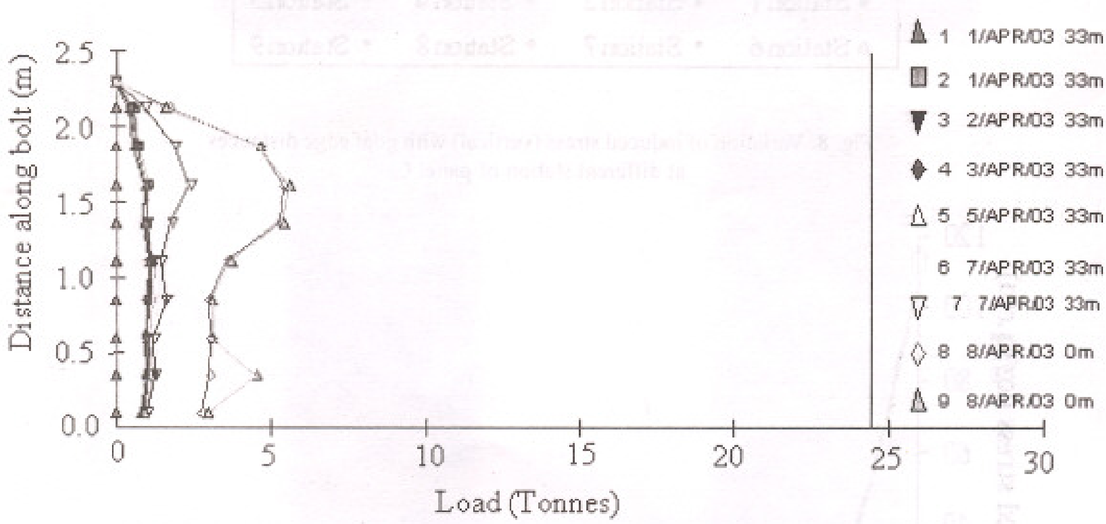

Fig. 7b: Development of axial load across a roof bolt of last row (working side) of a breaker line at different stages of a depillaring in panel 'C'

MINING INDUCED STRESS

To observe the nature and amount of mining induced stress over pillars, a number of stress meters were placed at certain intervals inside the horizontally drilled hole across pillars. After some experience, only one or two stress meters were installed in the pillar in such a way that it picks up the maximum amount of stress. This exercise is important to minimize the consumption of the instrument.

Variation of the induced vertical stress with goaf edge distance at all the selected stations of the panel is shown in Fig. 8. This figure represents variation of the stress with respect to face positions so the peak of stress is a bit scattered. This is mainly due to the fact that the zero position of the face with respect to the instrument did not always match with the main roof fall. The strata movement is the main reason for dynamic loading of the natural support i.e. pillars. Considering this fact, the stress development was normalized and the zero position of the face was shifted to peak value of the mining induced stress. The exercise was done mainly to correlate the stress development with the major strata movement. Further, the data was subjected to statistical analysis for a better correlation. Most of the unreasonable data were eliminated during the process and the final shape of the stress variation with face position is given in Fig. 9.

Here, it is presumed that the zero position of the instrument matches with the main roof fall. The obtained equation for estimation of mining induced stress for the depillaring panel is:

$$S = 39.993\, e^{-0.058x} \quad ....(1)$$

Where, S is mining induced stress (vertical) in kg/cm^2 and x is face position from the goaf edge in m.

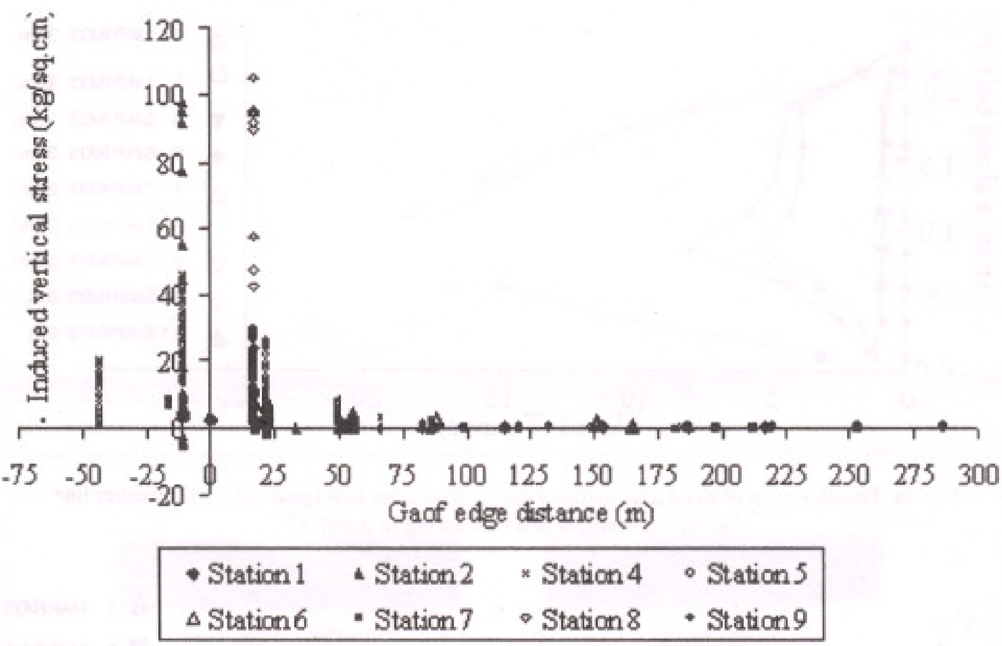

Fig. 8: Variation of induced stress (vertical) with goaf edge distances at different station of panel C

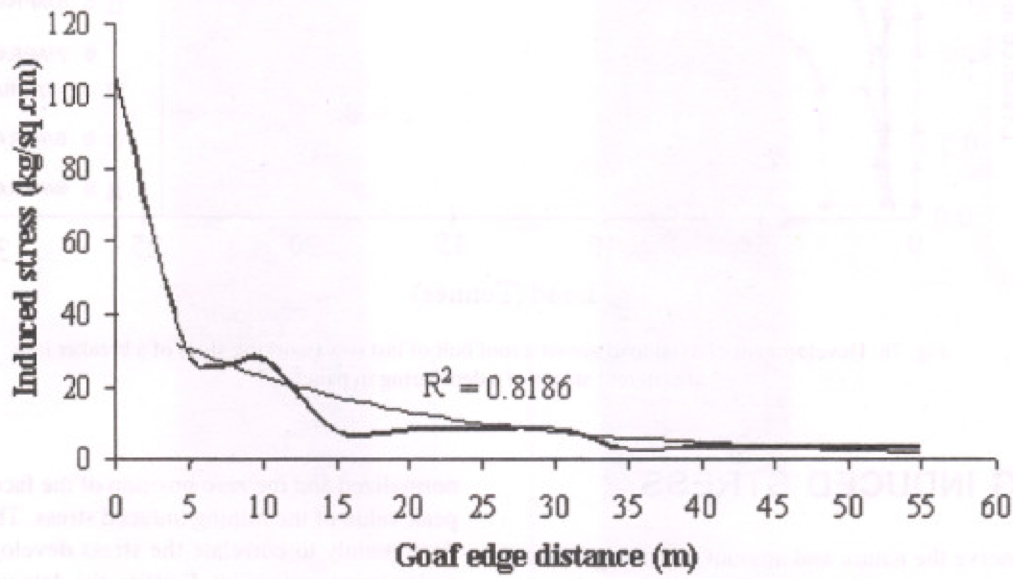

Fig. 9: Projected nature of variation of mining induced stress (vertical) under the geo-mining condition of Anjan Hill Mine

This nature of the variation finds better fitting for the data when the distance is more than 10 m. The sharp rise in the value between 10 to 0 m is mainly due to *en masse* movement of the roof strata due to high extraction ratio.

ROOF TO FLOOR CONVERGENCE

Convergence observations in the same depillaring panel at different selected locations are presented in Fig. 10. An exercise, similar to that of mining induced stress observations, was done for convergence observations and final shape of the convergence change is shown in Fig. 11. The equation obtained through regression for estimation of cumulative convergence in the depillaring panel is given as:

$$C = 49.532\, e^{-0.071x} \quad ....(2)$$

Where, C is cumulative convergence in mm.

Again, the sudden increase of convergence near zero line (roof fall) is mainly due to the *en masse* strata movement during the fall. At zero line, there is no effective natural support so the convergence shoots up just before the fall.

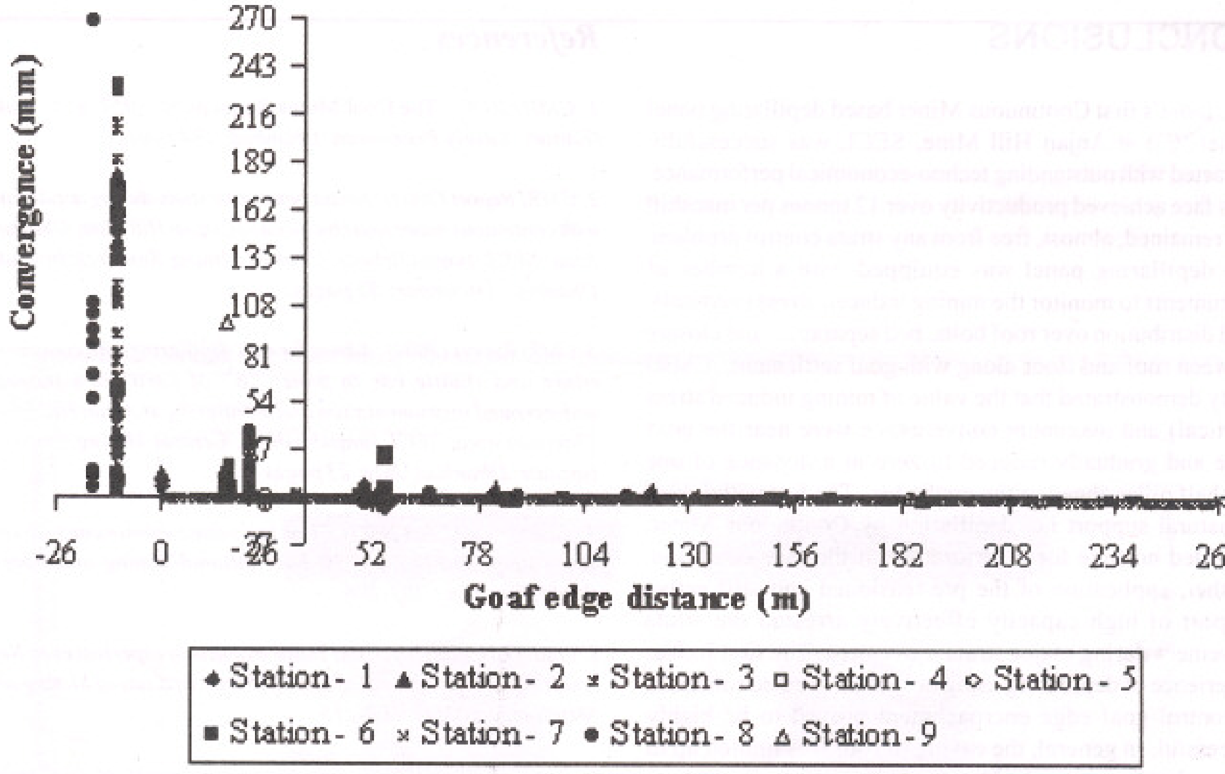

Fig. 10: Convergence observation with goaf edge distances at different station of panel 'C'

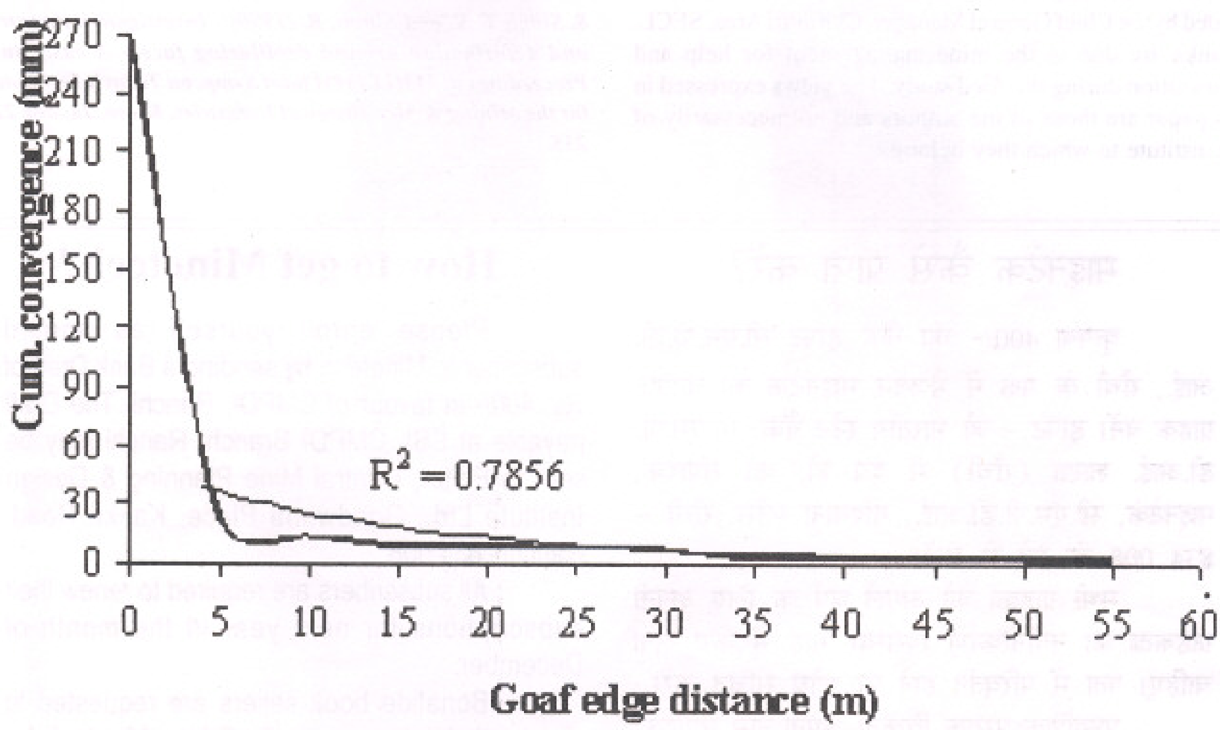

Fig. 11: Projected nature of roof to floor convergence during depillaring of panel 'C'

CONCLUSIONS

India's first Continuous Miner based depillaring panel (panel 'C') at Anjan Hill Mine, SECL was successfully extracted with outstanding techno-economical performance. This face achieved productivity over 12 tonnes per manshift and remained, almost, free from any strata control problem. The depillaring panel was equipped with a number of instruments to monitor the mining induced stress (vertical), load distribution over roof bolts, bed separation and closure between roof and floor along with goaf settlement. CMRI study demonstrated that the value of mining induced stress (vertical) and maximum convergence were near the goaf edge and gradually reduced to zero at a distance of one and half pillar ahead of the goaf edge. The fast withdrawal of natural support i.e. depillaring by Continuous Miner, provided no time for deterioration of the face condition. Further, application of the pre-tensioned and stiff active support of high capacity effectively arrested the strata movement during major strata movement. The first Indian experience of depillaring using only resin grouted roof bolts to control goaf edge encroachment proved to be highly successful. In general, the caving of roof was limited up to the breaker line supports. No premature failure (except two) ahead of the face was noticed during the extraction.

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