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Closing of a running mine and suggesting a new approach of winning of otherwise-left unextracted coal reserves

In the workable Rayatwari seam of CRC colliery, WCL, having thickness of about 17m, 2nd lift depillaring was reportedly completed in the year 2001. Till 2009, no activity was undertaken as the areas were known cases of poor stowing and in some areas 'no stowing' was done due to many technical and some non-technical reasons. At some worst places, the roof collapses exposed even the sandstone roof. The study, with an aim to find a solution and as described briefly in this paper, has assessed the associated risks, overlying roof strata and the general regional stability of the mine and also reasons for those. The low block safety factor contours in simulated models of the mine suggested the expected high rock load to be supported that was found unpractical to execute. Moreover, the re-supporting exercises would call for additional risk to men and machine and might not be feasible technically as well as economically. To provide an alternative to the mine life and also to provide ingress and egress to the dip-side coal reserves, it was recommended to drive at least two sets of galleries in coal, suitably located keeping the sandstone or the competent coal (if weak shale/weathered sandstone is encountered) in roof of these galleries. Subsequently depillaring of the developed coal reserves, but hitherto located inaccessibly at dip-side of main dip at the moment, may then be taken up. The Indian inspectorate supported the recommendations by CSIR-CIMFR and the mine has recently started implementing the same.

Keywords: Coal mining, numerical modelling, rock load, support system, mine reopening

1.0 Introduction

Successful extraction of thick coal seam has been a chronic problem for mine operators [1]. In India, thick coal seams with moderately caving strata have, by and large, adopted stowing as a method of goaf treatment. Stowing invariably provides better ground control for successive mining in sections within the same seam (if thick) or extracting multiple seams in ascending order [2]. An Indian coal mine named as Chanda Rayatwari Colliery (CRC), Chandrapur Area, Western Coalfields Limited (WCL, a subsidiary of CIL), is having only workable Rayatwari seam of 17 m thick. This coal seam, having gradient of 1in 5, was developed with average pillar size of 20m × 20m (centre-to-centre) and average gallery width of 4.0m. The seam section with different extraction-lifts has been shown in Fig.1. The seam was extracted by developing 2nd lift, leaving 2.54m (height) of floor coal as lower section was of poor quality (non-marketable) at those days (in 1954). The 2nd lift was depillared later on in the sectionalized panels for example, P1, P3 etc. on east side and B2, B3, etc. on west side of the incline nos. 1 and 2, and as shown in Fig. 2 in conjunction with stowing. During 2nd lift extraction, around 1m of floor coal was also extracted by floor-dinting, simultaneously with roof heightening such that after 2nd lift, about 6.35m coal [3m (2nd lift coal) + 1m (coal from floor dinting) + 2.35m (coal from roof heightening)] was extracted from the panel yet. Subsequently, 3rd lift was also extracted with stowing in few panels. It is to be noted that for better regional stability, only splitting as a final operation, as reportedly tried in 2nd lift coal extraction in conjunction with floor dinting and roof heightening has been done.

It was found upon the underground observations by the first and third authors that there were numerous occurrences of roof and side falls, especially at junctions. The roof coal after 3rd lift, wherever tried by the mine management, had a tendency to fall to the extent that sandstone present in the immediate roof were exposed at some instances. Due to such unsurmountable geotechnical problems, the extraction was ceased after 2nd lift for quite some years (since 2001), with reported inadequate stowing in some areas due to both technical and non-technical reasons. This had queer the pitch and fudged the chance of a feasible coal extraction from these locales, as apprehended by the mine management. The increased chances of spontaneous heating caused due to roof and side falls further aggravated the situations.

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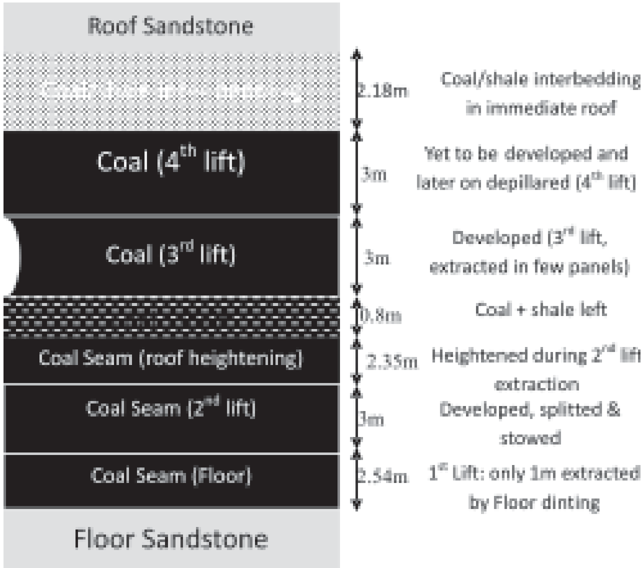


Fig.1 Scheme of extraction methodology followed in Rayatwari seam at CRC mine (not to the scale)

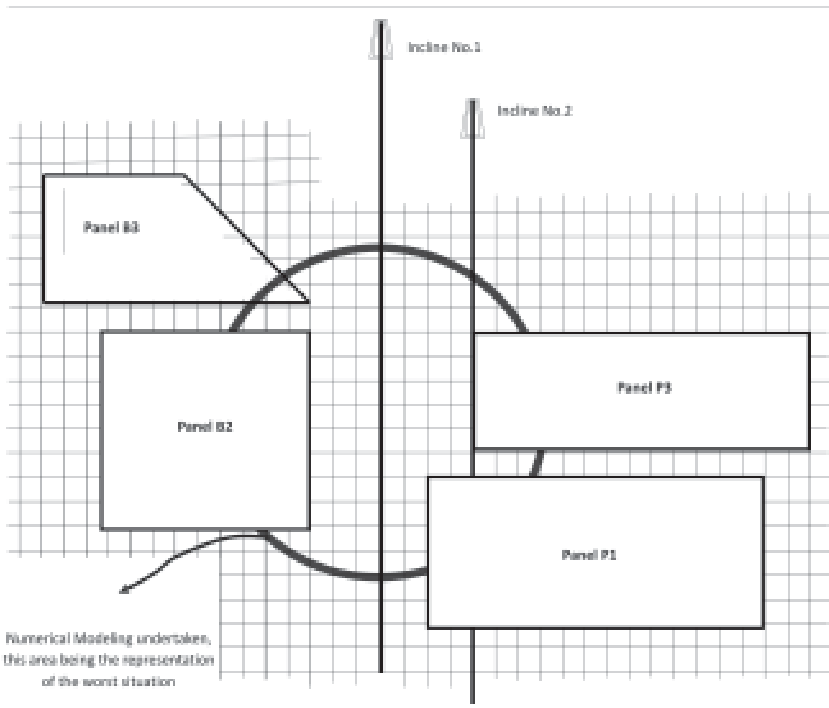


Fig.2 Schematic diagram of the existing access and egress galleries in CRC colliery, WCL (not to the scale)

The mine management contacted CSIR-CIMFR with the understanding that a pro-active approach to understand the geotechnical problems and a comprehensive scientific study would be conducted and a solution could be found out. In this paper, the assessment of geotechnical risk were taken up comprehensively, finding possibility as to whether further development and subsequent depillaring is feasible or not. The objective of this research study was to assess whether the worst situated workings (from geotechnical points of view), as marked by circle in Fig.2, would be safe or not. If not, the alternative need to be found out. As briefly discussed in the paper, the present mining method even for left-out developed coal reserves, situated in the dip-sides were not found feasible due to roof and side falls and cascading ground control problems. This paper, therefore, also deals with aspects of stabilization. After stabilization of the existing workings, new ingress and egress were recommended with support design, briefly discussed. The reopening of the coal reserves would help extraction of about 11 Mt of coal reserves with proper stowing in future.

2.0 Conceptual approach

Rock and coal samples from the area, being inaccessible due to roof/side falls, could not be collected. The first author had the rock/coal properties evaluated during his earlier research association in the CRC colliery area and therefore those details were gainfully utilized in this study as given in Table 1 of the next section of this paper.

No empirical formulation is available to assess the associated risk and the regional stability of the mine. The only option left for a researcher in such cases is to go for numerical modelling where the mine workings need to be simulated, to estimate the stability of workings for situations with poor or no stowing. This study thus analyzed, the best and the worst situation of stowing with view to assess roof rock behaviours leading to roof falls in the mine. Moreover, the study also finds an answer to the question as to how safe a workings would be if stabilization with sand stowing would have been implemented.

The support safety factor (SSF), more than 2.0, has been considered to design the support system in the new development of ingress and egress as the recommended supports would provide safety on long-term basis, also for future extraction proposition for the dip-side developed coal reserves. The main dip galleries, in CRC colliery, were found to be unsafe, perhaps due to adjoining (both-side) goaves with 'no or poor stowing', as manifested in humongous and pervasive roof and side falls.

3.0 Numerical modelling

Finite difference based FLAC3D of Itasca Consulting Group Inc., Minnesota, USA have been used for modelling. The plane of symmetry serves as a handy tool in reducing the extent of modelling, optimizing the computational space and time requirements without compromising on the efficacy of the results [3]. It provides a mirror image of area being modelled across the plane of symmetry. Had the numerical models been made for the whole mine workings i.e., without the use of symmetry-planes, the results would be the same. The goaved out panels were considered in both the cases to simulate real mining scenario as prevalent in mines using the concept of symmetry as shown in Fig.3. Sheorey failure criterion developed for Indian coal measure rock and coal seams have been used for simulating the failure of roof rock masses and coal seams [4, 5].

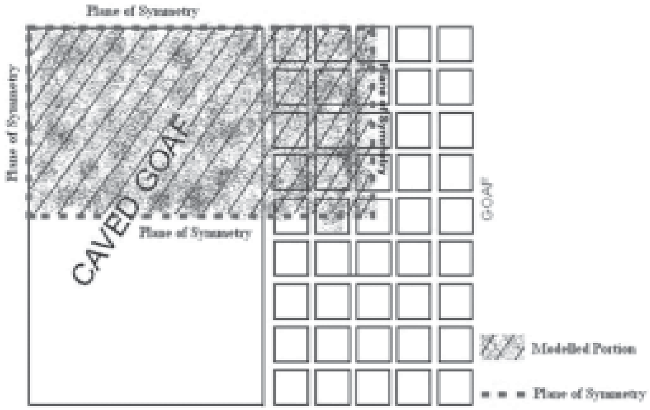


Fig.3 Modelled portion for simulating goaves and existing access and egress galleries (not to the scale) (refer Fig.2)

3.1 In-situ stresses

In-situ stress conditions prevailing at a mine site is an important input parameter which affects the results of numerical modelling [6]. An in-situ stress-values prevalent in Indian coal seams were considered for modelling [5, 7, 8]. The in situ horizontal and vertical stresses are given in eqns. (1) and (2) respectively for Indian coalfields [6]:

$$S_H = S_h = 2.4 + 0.01H, \text{ MPa} \quad \text{...} \quad (1)$$

$$S_v = \gamma H, \text{ MPa} \quad \text{...} \quad (2)$$

where, S_H and S_h are the major and minor horizontal in-situ stresses, MPa, γ = unit rock pressure, 0.025 MPa/m and H = hard rock cover below surface, m.

3.2 Sheorey's failure criterion

A failure criterion proposed by CSIR-CIMFR for intact rock was used to estimate the safety factor of each element used in the model, which is reproduced as [4]:

$$\sigma_1 = \sigma_c \left(1 + \frac{\sigma_3}{\sigma_t}\right)^b \quad \text{...} \quad (3)$$

where, σ_1 and σ_3 are major and minor principal stresses at failure, σ_c and σ_t are the laboratory compressive strength and tensile strength, b is the exponential constant for the intact rock.

Understandably, the intact rock/coal properties are much more than those of rock masses since, the latter consists of joints/fractures etc. The cubical samples generally tested in laboratory are free from any such features and hence the strength values of the intact samples need to be suitably reduced for those of rock masses having discontinuities and plane of weaknesses. The eqn. (3) for intact rocks may therefore be transformed for rock mass as:

$$\sigma_1 = \sigma_{cm} \left(1 + \frac{\sigma_3}{\sigma_{tm}}\right)^{b_m} \quad \text{...} \quad (4)$$

where, σ_1 and σ_3 are major and minor principal stresses at failure, σ_{cm} = uniaxial rock mass compressive strength, MPa, σ_{tm} = rock mass tensile strength, MPa, b_m = exponent in failure criteria for rock mass.

These constants are related to the Bienawski rock mass rating (RMR). The RMR values are determined based on layer thickness, structural features, rock weatherability, rock strength and groundwater seepage [9]. It has been observed that the rock strength is reduced exponentially to simulate rock mass behaviour. It can be inferred from the formulations that, if the RMR value is high, the reduction of the strength values for rock masses will be less. Obviously, high RMR means better rock conditions [5, 9].

3.3 Input parameters for modelling

The coal seam has been modelled considering the material properties as listed in the Table 1. The parameters includes elastic constants, Poisson's ratio and density, which are essential values for true simulation of numerical models and numerical modelling studies. Compressive strength, b and Bienawski RMR values are required for calculating block safety factor contours [9]. For numerical modelling purpose, the unadjusted RMR has to be used since the numerical model itself takes into account the adjustment of factors as per the simulation exercise undertaken.

It is to be noted that the modelling did not take into account the post-failure characteristics, neither elasto-plastic or plastic or dis-continuum modelling were undertaken by the authors for this study. With nil post-failure values, the elastic

Table 1: Average properties used in the modelling

Rock type	Modulus of elasticity, E, GPa	Poisson's ratio, v	Rock density, ρ, kg/m^3	Intact compressive strength, σ_c, MPa	RMR
Sandstone	10.0	0.25	2548	40	41
Coal seam	2.0	0.25	1300	24	25
Stowing#	0.65	0.1	1500	–	–

Note: The modulus of elasticity for sand stowing as a goaf treatment material, is found to be much less as compared to that of hard rock bed including coal. The lower value has been estimated from non-linear goaf compaction using theoretical model by [10] by back calculation.

modelling exercises, undertaken here, would simulate the worst-situation. Had the encouraging results been obtained by elastic modelling, the advanced numerical modelling i.e., elasto-plastic or strain softening modelling would have been tried for such situation.

3.4 Modelling stages

The numerical simulation studies were undertaken in following stages:

Stage 1

The grids were suitably generated to simulate the workings of CRC colliery, WCL. The virgin model was loaded with in-situ stress values, density, requisite boundary conditions and different rock properties (layer-wise) as given in Table 1.

Stage 2

Development of roadways in coal seam were done as per modelled mine geometry (16m × 16m, corner to corner) and model were run to estimate the vertical stresses coming over pillars and (4.0 m) galleries. After simulation of developed workings, conditions with final extraction of bottom 6m of the seam with poor stowing has been shown in Fig.4.

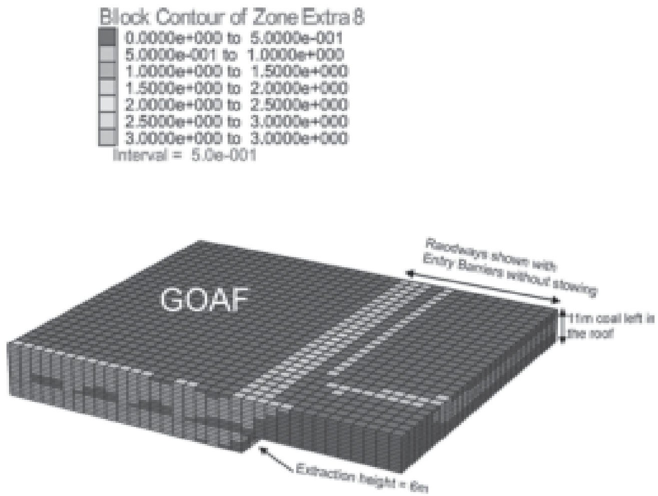


Fig.4 Bottom 6m of coal seam, extracted but very poorly stowed

4.0 Modelling results and discussion

The workings and geomining conditions of circle as shown in Fig.2, with poor stowing conditions were simulated using FLAC3D platform. The block safety factor contours for extraction of 6m coal in the bottom section are shown in Fig.4 with no stowing, where it can be observed that the block safety factor contours (FOS≤1.0) for no stowing case reaches 11m above the immediate roof horizon, covering the entire left-over coal seam and making it likely to fail.

It was mandated to the mine to start coal production at the earliest for non-technical reasons such as (a) non-shifting of employees to other mine, (b) continue to meet social obligation for employment, etc. In order to reopen the mine, it needs to be stabilized with proper stowing first, and to validate by scientific surface subsidence monitoring. No coal evacuation/production should be done by the mine management before stabilization is successfully done and monitored from surface. The stabilization is also to be done as there are important surface properties (inhabitant-dwellings, waterbodies, etc.) which need to be protected. In order to increase the mine life and extract the left-out coal reserves, a new set of ingress and egress to the area needs to be made. Two set of galleries are to be suitably driven, keeping sandstone or coal (where such sandstone is not available, 1m thick) as roof of these galleries. It is to be noted that the mine has been reopened recently after stabilizing the old workings as suggested in this paper and has resumed coal production.

5.0 Design of ingress and egress galleries

In order to determine the optimum dimensions of the ingress and egress, two variations of numerical modelling were undertaken with roadway sizes of (i) 3.5m wide × 3.0m height and (ii) 4.0m wide × 3.0m height. The results of these numerical modelling were analyzed and suitable support designs were suggested. The modelling were done with same grid as discussed in section 3.4 above. The development has been made along the sandstone roof.

5.1 Support design

The immediate roof along the roadway galleries meant for ingress and egress need to be supported with required SSF of 2.0 or more. The rock load, *P*, required to be supported is given by eqn. (5) as:

$$P = \gamma \chi h_{SF=1.0} \quad \ldots \quad (5)$$

where, P = Rock load to be supported, t/m^2, γ = rock density, t/m^3, and $h_{SF=1.0}$ = rock load height of block safety factor contour ≤ 1.0 (from numerical models).

The applied support load (*ASL*), for support design during development can be determined by eqn. (6) as:

$$ASL = \frac{n * b_c}{B * S_p} \quad \ldots \quad (6)$$

where, n = is the number of resin bolts in each rows, b_c = roof resin bolt capacity, B = roadway width, (m), and S_p = spacing between two rows.

$$\text{Support safety factor (SSF)} = \frac{ASL}{P} \quad \ldots \quad (7)$$

5.2 Stability of new ingress and egress roadways

From the numerical modelling studies conducted for estimating the stability of ingress and egress roadways in two situations with width of 3.5m and 4.0m, different rock loads in roadways and junctions were found from the block safety factor contours. The support design have been done with resin grouted bolts having reinforcement capacity of 12t and

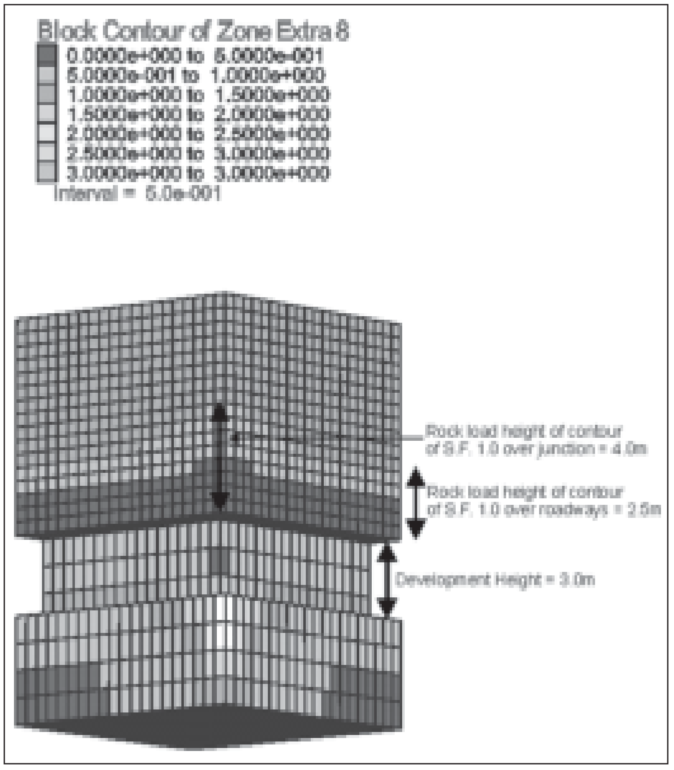


Fig.5 Block contours of safety factor in new development roadways (3.5m width × 3m height) over stowed lower sections-workings

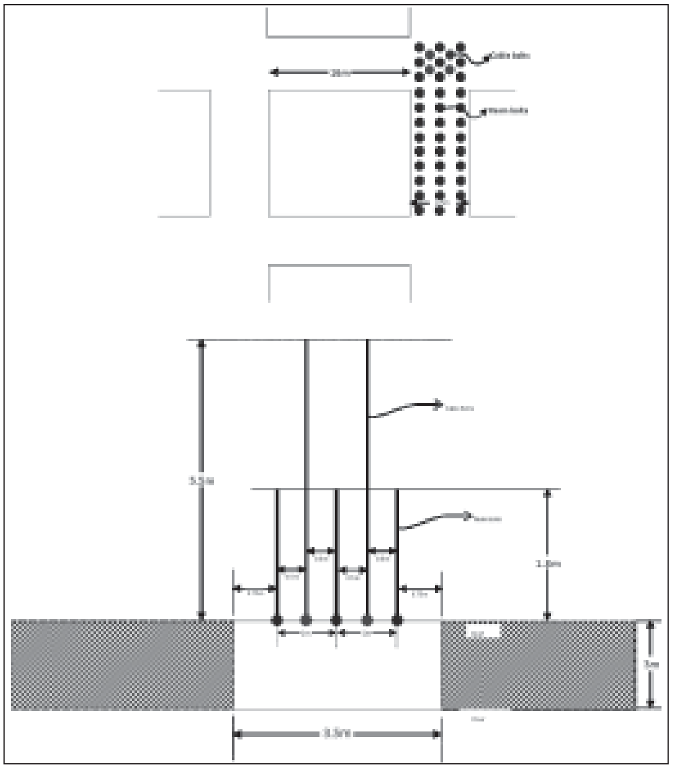


Fig.6 Support design of a roadway 3.5 m (width) with sandstone roof

cable bolts with reinforcement capacity of 8t at an spacing of 1.0m between consecutive rows.

Case 1: Roadways sizes 3.5m wide × 3.0m height

The block safety factor contours is shown in Fig.5. It can be seen from Fig.5 that the block safety factor contours for FOS=1.0 (minimum required for safety) extends upto 2.5m in the roadways and up to 4.0m at the junctions. For stability of the workings, the SSF of 2.0 is considered. The required support load is 5.2t/m^2. In 3.5m wide galleries, 3 resin grouted bolts of 1.8m length have been used in conjunction with 2 cable bolts of 6.5m length as shown in Fig.6.

The support resistance offered = (3*12)/(3.5*1) + (2*8)/(3.5*1) = 14.85 t/m^2

SSF = 14.85/5.2 = 2.85

Case 2: Roadways sizes 4.0m wide × 3.0m height

The block safety factor contours is shown in Fig. 7. It can be seen from Fig.7 that the block safety factor contours for FOS=1.0 reaches upto 3.0m in the roadways and up to 5.0m at the junctions. For stability of the workings, with SSF of 2.0, the required support load is 6.5t/m^2. In 4.0m wide galleries, 4 resin bolts of 1.8m length have been used in conjunction with 2 cable bolts of 6.5m length as shown in Fig.8.

The support resistance offered = (4*12)/(4*1) + (2*8)/(4*1) = 16 t/m^2

SSF = 16/6.5 = 2.46

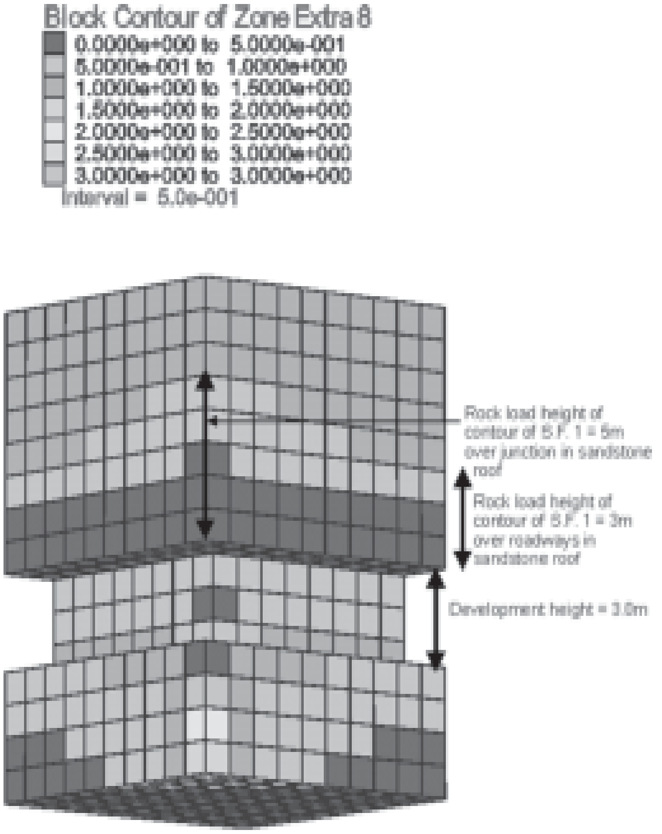
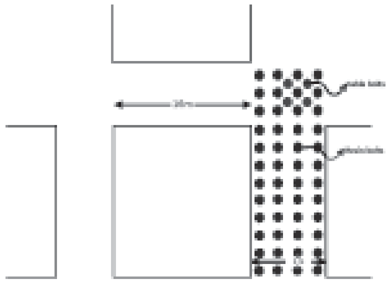


Fig.7 Block contours of safety factor in new development roadways (4m width × 3m height) over stowed lower sections-workings



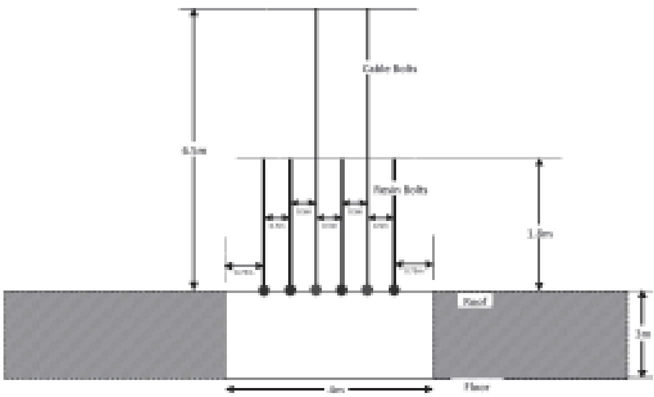


Fig.8 Support design of a roadway 4m (width) with sandstone roof

In both the cases, the SSF of reinforcement offered is more than 2.0 which will provide long term stability. Additional support reinforcement with the use of W-straps in roadways and wire-netting at junctions should be done which have not been shown in the Figs. 6 and 8. This suggests that the ingress and egress galleries would be stable.

6.0 Conclusions

About 6.35m of extraction height out of 17m thick Rayatwari coal seam was not stowed with sand, though the method of mining so warranted. This had significant adverse impacts on the developed workings above this. Over the period when the workings were disused, the situation further worsened. The results of numerical modelling validated these observations and the study thus concluded that the old workings including the main dip should be stabilized by back-filling. The efficacy of stabilization should be confirmed by surface subsidence monitoring and then new ingress and egress are to be driven with suggested support system (Figs.6 and 8). On a happy note, the mine is reopened as recommended and coal production is resumed. A word of caution in case of notable change of geology and geo-mining conditions is that the aspects of ground control and support system need to be revisited and reinforced with additional supports as necessary. The aspects of fire/spontaneous heating should be re-assessed, as was done under a separate CSIR-CIMFR scientific study. To conserve the space, that has not been dealt in this paper. It is expected that ethical practices of 'proper' stowing, constant vigilance and monitoring of strata movement behaviour and management would keep and maintain ‘no adverse’ mining-induced subsidence impacts on important surface properties – the habitants, water bodies, etc.

7.0 Acknowledgements

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