EXTRACTION OF THICK COAL SEAMS

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ABSTRACT

Numerical model studies on stress analysis during depillaring of 5-11m thick coal seams at depth range of 150-900m at an interval of 150m. Finite Difference Code – FLAC (fast Lagrangian analysis for continua) was used for understanding the influence of depth and thickness of coal seams on stress distribution over pillars, stooks and ribs at development stage and depillaring stage through parametric studies. 24 numerical models with different configuration representing the parameters in field experimental trials are used. Variables of the parametric studies for stress analysis are: seam thickness in the range of 5 – 11 m at an interval of 2 m and depth cover of 150 m to 900 m at an interval of 150 m. The maximum on pillar was found to be 35 MPa at 900m depth in 5m thick seam and the minimum was 5 MPa at 150 m depth. The maximum stress on stooks and ribs was found to be 70 MPa and 10 MPa in 5 m, 7 m at 900 m and 450 m depth respectively. From model it was found that thickness of the seam does not have any effect on the stress behavior of the pillars after development work. Parametric studies through the numerical models indicated decreased vertical stress over the stooks with increasing height of the extraction at the depth covers in the range of 150-900 m. Though the stress coming was less, the stooks were getting yielded very soon due to increase in height of the stook and increase in height to width ratio.

KEYWORDS: ***Numerical Model, Stress, depillaring, thick seam, stress analysis***

1.1. INTRODUCTION

Around 70% of the total coal reserves of India are excavated by underground mining methods only.[1] But underground extraction of coal could not achieve much importance due to the difficult geo-mining conditions of the coal deposits and unavailability of adequate engineering support to meet the required level of safety and rate of production. Although underground extraction of coal is considered as a part of CCT (clean coal technology), the share of coal production in the country by opencast mining has been continuously increasing during the last 50 year.[2] Fast mechanization of mines, short set-up gestation period, and high production and productivity are the main reasons behind the growth of coal production by opencast mining.[3] As the coal reserves suitable for extraction by opencast mining are becoming fewer in number, mining methods for safe and effective underground winning of coal are going to play an important role in future coal production. In India, coal seams of 4.8m thickness or higher are called thick. Nearly 60% of the total coal reserves that are workable by underground mining methods in the country are thick coal seams.[4] To fulfill the increasing demand of coal, most of these thick coal seams have been developed extensively in single or multiple slices/sections. Around 30% of the developed thick seams are underneath a protected surface, while the remaining70% are available for caving subject to the availability of a suitable mining method to extract coal under the existing challenges of the difficult geo-mining conditions.[5] Thick seams are found in many countries, e.g., the former USSR, France, Spain, China, former Yugoslavia, Canada and India, etc. In India, over 60% of all known coal reserves are contained in thick seams. Some of these thick seams are nearly 30 m thick. One exceptionally thick seam in Singrauli Coalfield is 162 m thick.[6]

2. REVIEWS

2.1. Problems associated with mining of thick coal seams

Following problems are associated with thick seam mining
1) Difficulty in strata control and its monitoring.
2) Risk of overriding of pillars leading to premature collapse (in case of bord and pillar workings)
3) Low percentage extraction, usually < 50% when extraction is done by bord and pillar method.
4) Chances of high spontaneous heating because of considerable coal loss in goaf.
5) Heavier support requirement in deep seams and longwall method of working.
6) Difficulty in subsidence control due to high magnitude subsidence.

2.2. Methods of mining thick coal seams

A general classification of methods of mining thick seams is summarized in Fig. 1.
Several modifications/variations to these methods are also tried in different mines as mentioned below.[7]

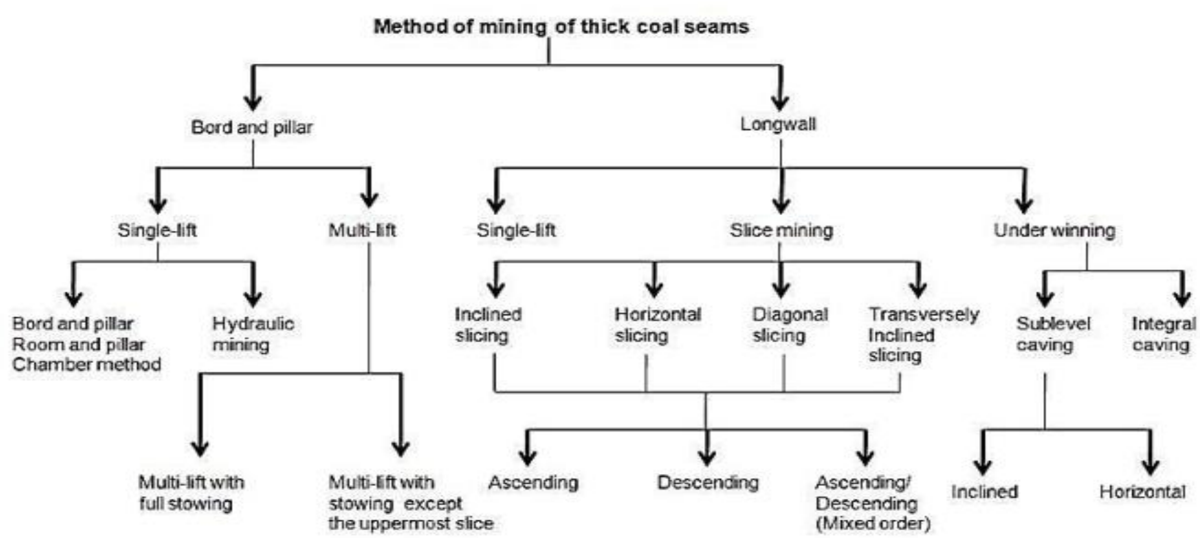


Fig. 1 General classification of thick seam mining methods (Singh, 1997)

Slice mining

In this method of mining a coal seam is divided into slices of appropriate thickness and each slice is worked in a method similar to that of an entire seam having thickness same as the slice. Coal from the slices can be extracted in ascending, descending or in mixed (both ascending and descending) order (Fig. 2).[8]

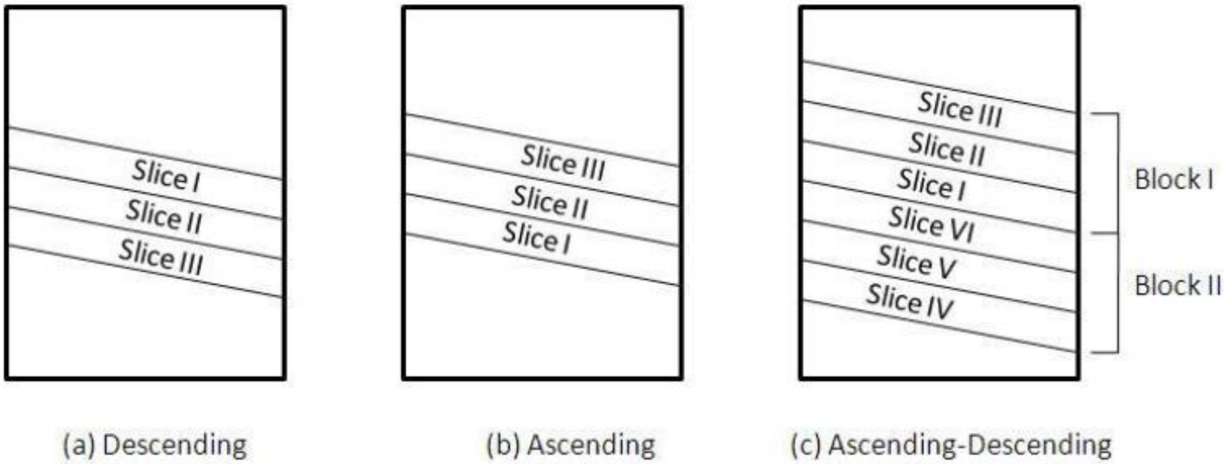


Figure 2: Different orders of slicing thick coal seams (Singh, 1997)

Descending slicing

Descending slicing can be done with or without stowing. In case of descending slicing with caving, spreading of wire netting is required to make artificial roof to arrest material of the broken goaf of the upper slice and this wire netting serves as the roof for the lower slices; i.e., lower slices are worked below the broken goaf. Stowing is rarely practiced in descending slicing.

Ascending slicing

In ascending slicing method, the first slice is the bottom most slice which is excavated first. Working of this slice is like working a seam of average thickness. Subsequent slicing is done with stowing, i.e., the upper slices are worked on the filled surface of the bottom slice and therefore ascending slicing cannot be adopted with caving. The last slice can be worked either with stowing or caving.

Mixed order slicing

In this method coal seam is divided into blocks, each block consisting of a number of slices. The slices in the block are worked in ascending order with stowing, while the blocks are worked in descending order. This method is commonly practiced in horizontal slicing method of thick seam mining.

Sublevel Caving

Sublevel caving is applicable to thick seams with caveable roof and soft coal, though by blasting, hard roof can also be caved and hard coal seams can be softened. This system is consists of (i) mining a slice along the roof by normal longwall method with caving with flexible artificial roof laid on coal along the floor of the first slice; (ii) mining of another slice along the floor of the seam, and (iii) taking down the coal parting between the two slices by longhole blasting which is loaded out in a conveyor laid along the floor of the seam. Figure 3shows the method of mining a 6.6 m thick coal seam by sub-level caving. In this method a longwall face takes a slice of 1.8 m along the roof of the seam. As the face retreats wire netting over steel bands is laid on the floor to form artificial roofing.[9] Some 30 m behind the top face, another longwall face takes a slice of 1.8 m along the floor. The middle coal plate which is usually thicker than the top and bottom slices is mined at a distance of 3.5 m behind the floor longwall face by blasting with long shotholes drilled from under the support of the lower face. The slope of the longwall face of the middle slice should be tilted back with respect to the face by 5-10° from the vertical in the direction of advance of the face. The artificial roof prevents the caved stone from mixing with the coal of the middle plate. The mining in the lower and upper slices can be mechanized by shearers.

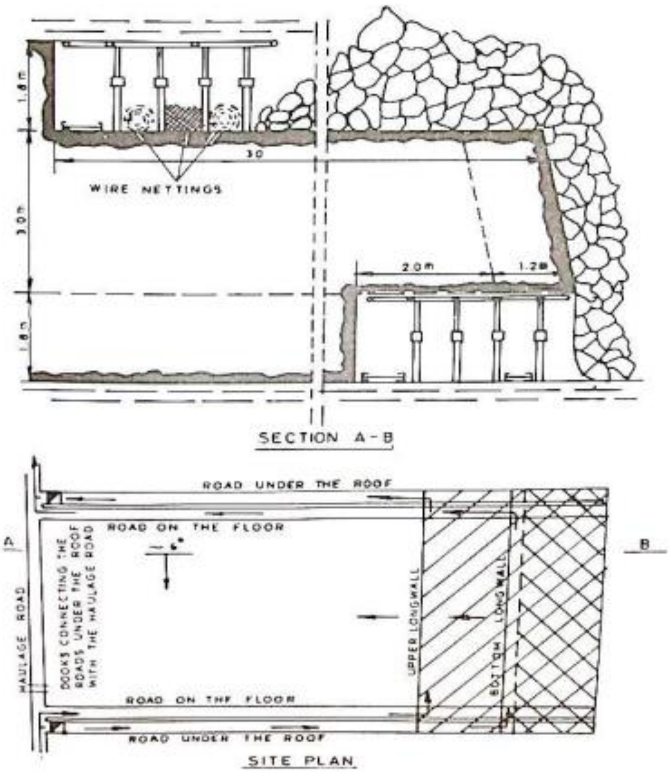


Figure 3: Diagrammatic layout of mining a thick seam by sub level caving (Kasparek1964) (Singh, 1997)

Integral caving

The recent development is full 'Soutirage' working or integrated sublevel caving, i.e., recovering in a single operation all the coal of the seam from a face progressing on the floor.[10] Figure illustrates this system of mining. The advantages of this method are:

1. The development costs and the investment in face equipment are well below those required for the method of slices parallel tc stratification, and this advantage is still further increased by the fact that greater seam thicknesses may be worked.
2. Some coal, which increases with the increasing seam thickness, is extracted by itself by the strata pressure resulting from the winning operations.
3. Automation of support system, with articulated roof bars known as 'banana.
4. Small number of faces can produce large quantity of coal.

5. Supervision is simpler and, therefore, there is greater efficiency of engineers and Overman, *etc*.
6. OMS is high say, up to 20 tones.

3. NUMERICAL MODELING

3.1. Flac

"FLAC is a two-dimensional explicit finite difference program for engineering mechanics computation.[11] This program simulates the behavior of structures built of soil, rock or other materials that may undergo plastic flow when their yield limits are reached. Materials are represented by elements, or zones, which form a grid that is adjusted by the user to fit the shape of the object to be modeled. Each element behaves according to a prescribed linear stress/strain law in response to the applied forces or boundary restraints. The material can yield and flow and the grid can deform (in large-strain mode) and move with the material that is represented. The explicit, Lagrangian calculation scheme and the mixed discretization zoning technique used in *FLAC* ensure that plastic collapse and flow are modeled very accurately. Because no matrices are formed, large two-dimensional24calculations can be made without excessive memory requirements.[12] The drawbacks of the explicit formulation (i.e., small time step limitation and the question of required damping) are overcome to some extent by automatic inertia scaling and automatic damping that do not influence the mode of failure."

3.2. Comparison with other methods

How does *FLAC* compare to the more common method of using finite elements for numerical modeling? Both methods translate a set of differential equations into matrix equations for each element, relating forces at nodes to displacements at nodes. Although *FLAC*"s equations are derived by the finite difference method, the resulting element
matrices, for an elastic material, are identical to those derived by using the finite element method (for constant strain triangles). However, *FLAC* differs in the following respects:

1) The "mixed discretization" scheme[13] is used for precise modeling of plastic failure loads and plastic flow. This scheme is believed to be physically more reasonable than the "reduced integration" scheme commonly used with finite elements.
2) The full active equations of motion are used, even when modeling systems are real static. This enables *FLAC* to follow physically unstable processes without numerical distress.

3) An "explicit" solution scheme is used (in contrast to the more usual implicit methods). Explicit schemes can follow arbitrary nonlinearity in stress/strain laws in almost the same computer time as linear laws, whereas implicit solutions can take significantly longer to solve nonlinear problems. Furthermore, it is not necessary to store any matrices, which means that: (a) a large number of elements may be modeled with a modest memory requirement; and (b) a large-strain simulation is hardly more time consuming than a small-strain run, because there is no stiffness matrix to be updated.

4) *FLAC* is robust in the sense that it can handle any constitutive model with no adjustment to the solution algorithm; many finite element codes need different solution techniques for different constitutive models.

5) *FLAC* numbers its elements in a row-and-column fashion rather than in a sequential fashion. For many problems, this method makes it easier to identify elements when specifying properties and interpreting output.

3.3. Recommended steps for numerical modeling

Step 1: Define the Objectives for the Model Analysis

The level of detail to be included in a model often depends on the purpose of the analysis. For example, if the objective is to decide between two conflicting mechanisms that are proposed to explain the behavior of a system, then a crude model may be constructed, provided that it allows the mechanisms to occur. It is tempting to include complexity in a model just because it exists in reality. However, complicating features should be omitted if they are likely to have little influence on the response of the model, or if they are irrelevant to the model's purpose. Start with a global view and add refinement as (and if) necessary.[14]

Step 2: Create a Conceptual Picture of the Physical System

"It is important to have a clear picture of the problem to provide an initial estimate of the expected behavior under the imposed conditions. Several questions should be asked when preparing this picture. For example, is it expected that the system could become unstable? Is the predominant mechanical response linear or nonlinear? Are movements expected to be large or small in comparison with the sizes of objects within the problem region? Are there well-defined discontinuities that may affect the behavior, or does the material behave essentially as a continuum? Is there an influence from groundwater interaction? Is the system bounded by physical structures, or do its boundaries extend to infinity? Is there any geometric symmetry in the physical structure of the system? These considerations will dictate the gross characteristics of the numerical model, such as the design of the model geometry, the types of material models, the boundary conditions, and the initial equilibrium state for the analysis. They will determine whether a three-dimensional model is required, or if a two-dimensional26model can be used to take advantage of geometric conditions in the physical system." [15]

Step 3: Construct and Run Simple Idealized Models

When venerating a physical system for numerical analysis, it is more effective to construct and run simple test models first, before building the detailed model. Simple models should be created at the earliest possible phase in a project to generate both data and understanding. The results can provide further vision into the conceptual picture of the system; Step 2 may need to be repeated after simple models are run. Simple models can reveal inadequacies that can be remedied before any significant effort is invested in the analysis. For example, do the selected material models sufficiently represent the expected behavior? Are the boundary conditions inducing the model response? The results from the simple models can also help guide the plan for data collection by identifying which parameters have the most influence on the analysis."[16]

Step 4: Assemble Problem-Specific Data

The types of data required for a model analysis include:
1) details of the geometry
2) locations of geologic structure (e.g., faults, bedding planes, joint sets)
3) material behavior (e.g., elastic/plastic properties, post-failure behavior)
4) initial conditions (e.g., in-situ state of stress, pore pressures, saturation); and
5) external loading (e.g., explosive loading, pressurized cavern).

Step 5: Prepare a Series of Detailed Model Runs

When preparing a set of model runs for calculation, several aspects, such as those listed below, should be considered.
1) How much time is required to perform each model calculation? It can be difficult to obtain sufficient information to arrive at a useful conclusion if model runtimes are excessive. Consideration should be given to performing parameter variations on multiple computers to shorten the total computation time.

2) The state of the model should be saved at several intermediate stages so that the entire run does not have to be repeated for each parameter variation. For example, if the analysis involves several loading/unloading stages, the user should be able to return to any stage, change a parameter and continue the analysis from that stage. Consideration should be given to the amount of disk space required for save files.

3) Are there a sufficient number of monitoring locations in the model to provide for a clear interpretation of model results and for comparison with physical data? It is helpful to locate several points in the model at which a record of the change of a parameter (such as displacement, velocity or stress) can be monitored during the calculation. Also, the maximum unbalanced force in the model should always be monitored to check the equilibrium or failure state at each stage of an analysis.

Step 6: Perform the Model Calculations

"It is best to first make two or more model runs split into separate sections before launching a series of complete runs. The runs should be checked at each stage to make sure that the response is as expected. Once we are assured that the model is performing correctly, several data files can be linked together to run a complete calculation. At any time during a sequence of runs, it should be possible to interrupt the calculation, view the results and then continue or modify the model as appropriate."

Step 7: Present Results for Interpretation

"The final stage of problem solving is the presentation of the results for a clear interpretation of the analysis. This is best accomplished by displaying the results graphically, either directly on the computer screen, or as output to a hardcopy plotting device. The graphical output should be presented in a format that can be directly compared to field measurements and observations. Plots should clearly identify regions of interest from the analysis, such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model. The numeric values of any variable in the model should also be readily available for more detailed interpretation by the modeler. We recommend that these seven steps be followed to solve geo-engineering problems efficiently.

The following sections describe the application of *FLAC* to meet the specific aspects of each of these steps in this modeling approach."

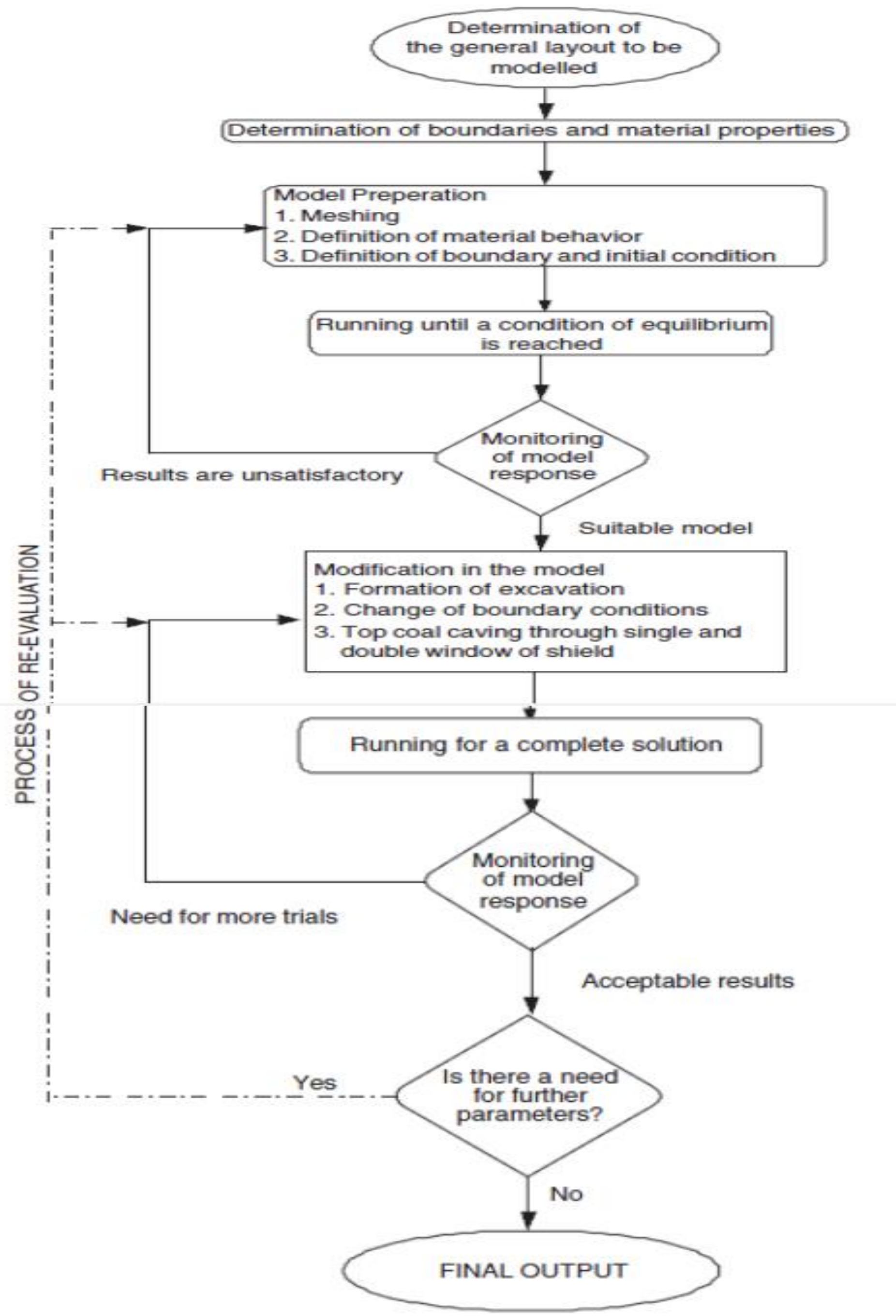


Figure 4: A general flowsheet of modelling procedure (Yasitli, 2002; Unver and Yasitli, 2002; Itasca, 1997).

4. METHODOLOGY

4.1. Numerical model parameters

Depillaring process in this numerical method includes different stages of division of pillars in to stooks and extraction of stooks upto full seam thickness leaving some ribs in the goaf. For two dimensional representation of full seam extraction in a seam, vertical section with four galleries in an idealized panel was selected (figure 7). A few parameters were kept constant for the model, e.g. width of the pillar, development gallery, split gallery and rib as 20.2 m, 4.8 m, 5 m, and 2.5 m respectively. Pillar size was kept constant at 25 m center to center in accordance with the average size in the field experimental trials. In the first stage of extraction, splits of 5 m width were provided. And the second, third and fourth stages of extraction include high opening upto full seam thickness with formation of ribs in the goaf. Stress conditions in these conditions were studied in numerical models.

4.2. The following sequence of the pillar development and excavations were simulated for all the above parameters:

1) Development of pillars (25 m center to center) (figure 7).
2) Splitting of three rows of pillars (figure 8).
3) Extraction of a row of pillars with a single rib inside the goaf (figure 9).
4) Extraction of two rows of pillars with two ribs inside the goaf (figure 10).
5) Extraction of two and a half row of pillars with two ribs inside the goaf (figure 11).
6) Extraction of two and a half row of pillars with a single rib inside the goaf (figure 12).

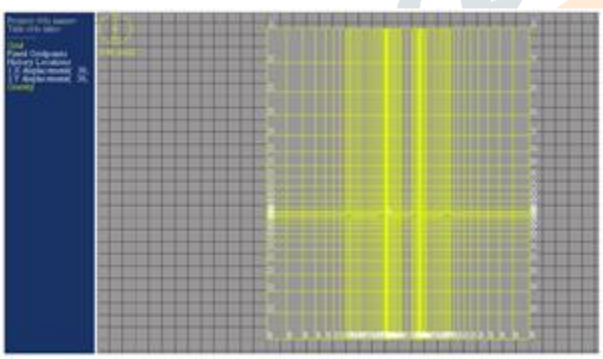


Figure 5 development of three pillars (25 m center to center) with four galleries (3x4.8 m)

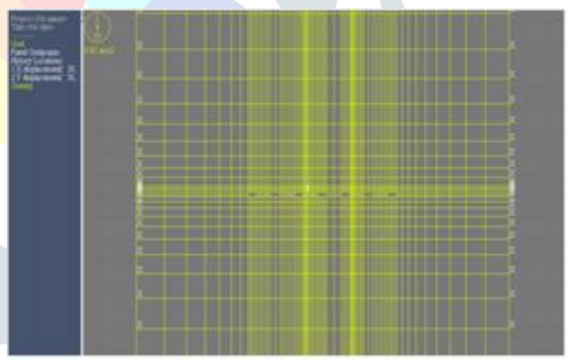


Figure 6 Splitting of three pillars

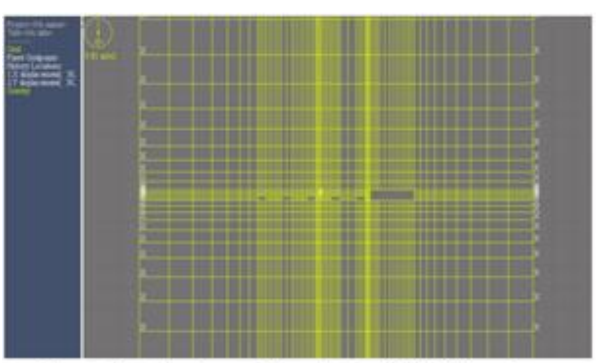


Figure 7 Extraction of a row of pillars with a single rib inside the goaf

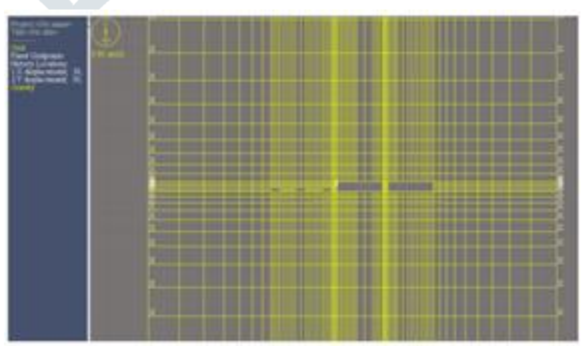


Figure 8 Extraction of two rows of pillars with two ribs inside the goaf

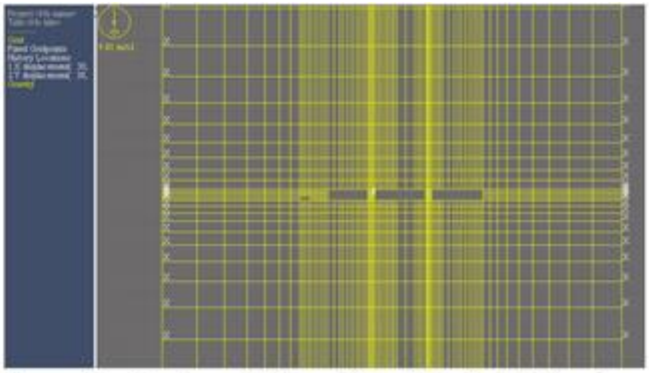


Figure9 : Extraction of two and a half row of pillars with two ribs inside the goaf

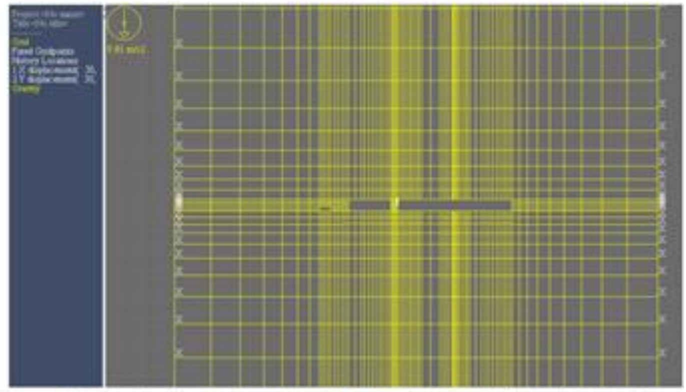


Figure 10 Extraction of two and a half row of pillars with a single rib inside the goaf

The top of model is free to move in any direction, and the bottom edge of the model is restricted from moving vertically. Roller type boundary conditions for all the models are placed along two edges of the models. In the absence of the in-situ stress measurement in the coal field, the following norms were adopted for estimation of in-situ stress field prior to the excavation of the area.

Vertical stress	= ρ x H
Horizontal stress	= 3.75 + 0.015 H

Where,

ρ = specific weight of the overlying rock mass and H = depth cover

The model has induced internal stress that simulates gravity loading. To generate pre-mining conditions before adding the mine openings to the input, the model goes through an initial analysis to generate the Insitu stresses. Gravitational and horizontal loading are forced on the other two surfaces in order to account for Insitu stresses. The displacements are reset to zero and the mine openings are added. The model is then reanalyzed to obtain the final stress distributions over the structures.

5. RESULTS AND ANALYSIS

5.1. Result

Table 1: Maximum vertical stress over pillar, stook and rib for different seam thickness and depth as per numerical model

Sr. No.	Depth (m)	Thickness (m)	Max. Stress (Pillar) (Mpa)	Max. Stress** (Stook) (Mpa)	Max. Stress** (Rib) (Mpa)
1	150	5	5	10	8
2	300	5	10	20	7.5
3	450	5	17.5	35	5
4	600	5	20	40	0
5	750	5	25	60	0
6	900	5	35	70	0
7	150	7	5	10	6
8	300	7	10	25.5	7.5
9	450	7	17.5	35	10
10	600	7	22.5	40	5
11	750	7	25	40	0
12	900	7	30	50	0
13	150	9	5	8	6
14	300	9	10	20	7.5
15	450	9	10	25	5
16	600	9	20	25	0
17	750	9	25	30	0
18	900	9	30	30	0
19	150	11	5	8	6
20	300	11	10	17.5	5
21	450	11	15	15	5
22	600	11	20	15	5
23	750	11	25	10	0
24	900	11	30	10	0

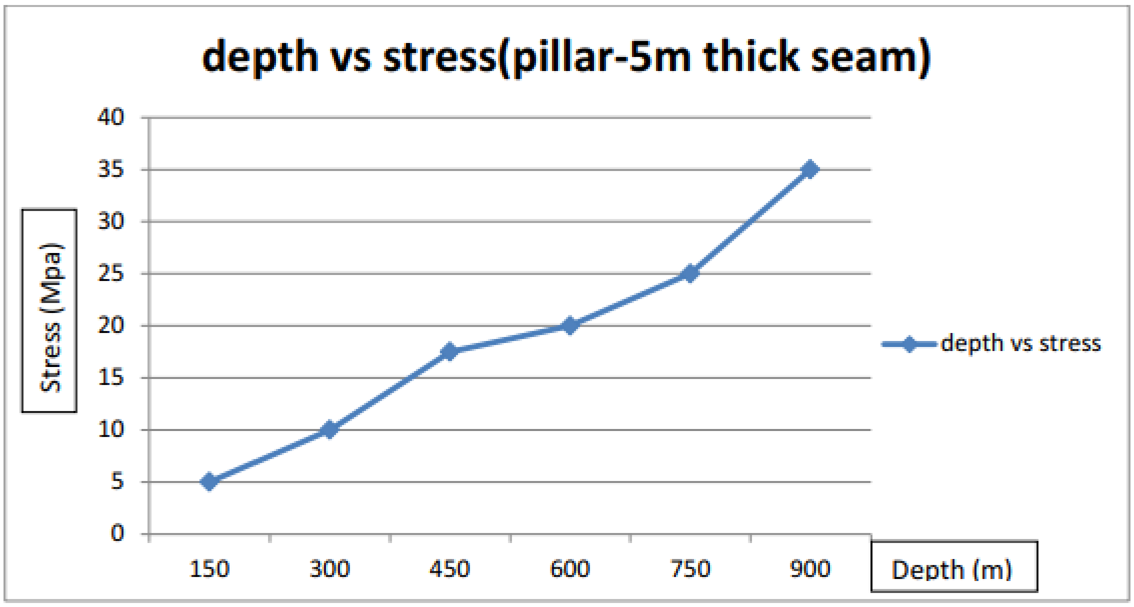
Table 2 : Results for depth vs maximum stress in pillars for various depths

Depth	Max. Stress (Pillar 5m) MPa	Max. Stress (Pillar 7m) MPa	Max. Stress (Pillar 9m) MPa	Max. Stress (Pillar 11m) MPa
150	5	5	5	5
300	10	10	10	10
450	17.5	17.5	10	15
600	20	22.5	20	20
750	25	25	25	25
900	35	30	30	30

Table 3: Results for depth vs maximum stress in stooks for various depths

Depth	Max. Stress** (stook 5m) MPa	Max. Stress** (stook 7m) MPa	Max. Stress** (stook 9m) MPa	Max. Stress** (stook 11m) MPa
150	10	10	8	8
300	20	25.5	20	17.5
450	35	35	25	15
600	40	40	25	15
750	60	40	30	10
900	70	50	30	10

** = Stresses on stooks or ribs after extraction of two and half pillars



Stresses on pillars after development work in 5m Thick Seams

6. CONCLUSION

Vertical induced stresses over pillars/stooks/ribs were guesstimated in extraction of pillars in a 5 to 11 m thick coal seam. Influence of depth cover and height of extraction that is thickness of seam was also studied through the two dimensional finite difference code FLAC. Based on the field and numerical model results, the following conclusions are drawn:

1) From the model results it was found that thickness of the seam does not have any effect on the stress behavior of the pillars after development work.

2) Parametric studies through the numerical models indicated decreased vertical stress over the stooks with increasing height of the extraction at the depth covers in the range of 150-900 m.

3) Though the stress coming was less the stooks were getting yielded very soon due to increase in height of the stook and increase in height to width ratio.

4) The model indicated decreased value of stress over ribs with increasing seam thickness at the depth cover in the range of 150-900 m. But the ribs were observed to be failing early as the extraction height increased.

5) This study also proves that as the height of extraction increases the structures gets yielded very early and fails soon. Though initially stress over them is less.

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