EXTRACTION OF CONTIGUOUS COAL SEAMS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology

In

Mining Engineering

By

ANUBHAV GAURAV

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DEPARTMENT OF MINING ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled, "**Extraction of Contiguous Coal Seams**" submitted by **Mr Anubhav Gaurav, Roll No. 107MN007** in partial fulfilment of the requirement for the award of Bachelor of Technology Degree in Mining Engineering at the National Institute of Technology, Rourkela (Deemed University) is an authentic work carried out by him under my supervision and guidance.
To the best of my knowledge, the matter embodied in the thesis has not been submitted to any University/Institute for the award of any Degree or Diploma.

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ABSTRACT

Underground mining methods are still used to excavate large proportions of coal in India. This accounts for up to 70 % of the total coal produced. The opencast is only profitable up to a certain depth; below that underground mining is the only profitable alternative. So more effective underground mining methods are required to be searched for and presented. When two seams are above one another, the workings in one tend to affect the working in another. In India coal seams that are near to one another such that the parting thickness between them is below 9 m are called contiguous. Coal mine regulation number 104 of Coal Mine Regulations, 1957 apply to such seams. The objective of this project was to evaluate the effect of parting thickness and depth cover of coal seams on stress distribution over pillars, stooks and ribs at different stages of depillaring, through numerical modelling using FLAC 2D software. Contagious seams can be extracted in three possible ways, viz, First extraction in the upper seam then followed by the lower seam, first extraction in the lower seam then followed by extraction in upper seam or simultaneous extraction of both the seams. In India such seams are extracted preferably by caving or stowing. For such seams when extracted the pillars of one seam shall be vertically above or bellow the pillars of other seam. In the example taken under consideration in this project, the two seams contiguous to one another were generated. Their depth cover (from 150 m to 750 m) and parting thickness (from 3 m to 9 m) were varied and the stress distribution over pillars, stooks, ribs and parting were evaluated. The evaluation was carried at two stages of mining, i.e. at development stage and after extraction of two and a half pillars with a single rib left. The maximum stress in the pillar increased with increase in parting thickness and depth cover. For stooks change in parting thickness was found to have no effects, while it increased with increase in depth cover. Maximum stress in ribs were found to be increasing with increase in parting thickness for top seam but remained more or less constant for bottom seam. While with increase in depth cover the maximum stress was found to be increasing first then decreasing. It can be inferred that the ribs may have yielded for larger depths.

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CHAPTER 1

INTRODUCTION

AND

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1. INTRODUCTION

Underground mining methods are still used to excavate large proportions of coal in India. This accounts for up to 70 % of the total coal produced. The difficulties as geological issues that arise in underground mining have made mining an unpopular industry. Sometimes the engineering design lags to cope up with the required safety standards and also reduced productivity is obtained. Due to these reasons open cast mining industry is on a rise. But the opencast is only profitable up to a certain depth; below that underground mining is the only profitable alternative. So more effective underground mining methods are required to be searched for and presented.

When two seams are above one another, the workings in one tend to affect the working in another. It has been found, for example, that in British coalfields, the pillars left in a seam 274 m above the one being worked has affected it.

In India coal seams that are near to one another such that the parting thickness between them is below 9 m are called contiguous. Such seams cannot be extracted as other general seams. Special permissions are required for such seams. Coal mine regulation number 104 of Coal Mine Regulations, 1957 apply to such seams. Several projects have been undertaken in India in contiguous seams as RK-8 incline of SCCL.

1.1 OBJECTIVE

To evaluate the effect of parting thickness and depth cover of coal seams on stress distribution over pillars, stooks and ribs at different stages of depillaring, through numerical modelling using FLAC 2D software.

CHAPTER 2

LITERATURE REVIEW

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2.1 LITERATURE REVIEW:

2.1.1 Contiguous seam mining:

The working of the seams may get affected if the distance between the seams is small. If there are two seams in such a manner that one seam is directly above the other one being worked, then the working in the top seam will definitely get affected. An example can be found in Raniganj coalfields where the working of Ponoati seam has severely affected the excavation in the working of the Koithee seam, which is about 40-45m above the former. Another example is Donets coalfields in former U.S.S.R. Here 'under mining' took place. According to one formulae by Shevyakov, 1958, if the distance between the two seams is lesser than 12 $h+3.5\ h^2$ (h, being the height of the seams in metres) then there remains a chance of under-mining.

If the seams are steep and the parting between them is small then even working in the upper seam may cause under mining in the lower seam. It has been shown by Scurfield,1970, that in British coalfields, the pillars left in a seam 274 m above the one being worked has affected it.

In India seams that are below 9 m apart are called contagious seams. For such seams, their workings have to abide by several statutory requirements that have been mentioned in Regulation 104 of Coal Mine Regulation, 1957. According to it, no work in a higher seam or section shall be done over in an area in a lower seam or section which may collapse. Also, it further mentions that where two or more such seams or sections are worked in a mine the pillars in one seam or section- shall, as far as practicable, be vertically above or below the pillars in the other seam or section unless the strata are inclined at an angle of more than 30 degrees from the horizontal, and the parting left between any two of such seams or sections shall not be less than three metres in thickness at any place.

2.1.2 *Possible alternatives for the extraction of contiguous seams*

Contagious seams can be extracted in three possible ways:

- First extraction in the upper seam then followed by the lower seam.
- First extraction in the lower seam then followed by extraction in upper seam.
- Simultaneous extraction of both the seams

2.1.2.1 *Extraction in the Upper Seam followed by the Extraction in Lower Seam*

The following effects appear if the upper seam is worked prior to the lower seam:

1. The roof in the upper seam gets settled.
2. The gob of upper seams may get filled with water.
3. If the seams are highly inclined and parting is less then there are possible chances of undermining. Also the strata breaks may extend from the upper seam to the lower seam and affect mining.
4. Crushing may occur if the parting between the seams is too less. As a result the goaf area of upper seam may puncture into the lower seam.
5. Migration of gases as firedamp, etc. may take place from lower seam to the upper seam, which may benefit us for a gas free lower seam working.
6. If we work out the upper seam first then distressing takes place in the lower seam giving us advantage if lower seam is prone to bumps.
7. More amount of subsidence and angle of draw may be faced for working under a ground broken by the upper seam working.
8. The lower seam cannot be worked until the upper seam has been completely exhausted.

2.1.2.2 *Extraction in the Lower Seam Followed by Extraction in the Upper Seam*

The following effects are to be expected for working in lower seam prior to the upper seam.

1. Undermining in the upper seam may take place. Problems as Uneven gradients, floor lifts and fractured roof may be faced while working in the upper seam as a result of prior excavation of the lower seam. Controls of such problems are extremely difficult.
2. Roof may cave even in the upper seam if the parting is less and as a result pillars may be lost forever.
3. Working in the lower seam may cause bed separation in the upper seam. This may prove to be advantageous while blasting of rocks.
4. If the parting is less then both seams can be worked out with one and same roadway and even if the lower seam has thinned out in certain areas, still its working will remain possible.

5. The surface effect in the seams may be violent but short lived if the working in the upper seam followed quickly the working in the lower seam.

2.1.2.3 ***Simultaneous Extraction in both the seams***

The following effects may be observed if the workings in both the seams are carried out simultaneously:

1. A good roof control can be obtained.
2. If working in the upper seams is done first there is a chance of inrushing water. But in this method it is possible to liquidate both the seams without any risk of such an inrush.
3. Even though the surface effects are violent, they are short lived. The surface in both the seams settles down quickly.
4. Since there is a simultaneous extraction of both the seams, a high output is obtained.

All the alternatives can be applied as per the requirement of the situations. None of them are universally applicable. Generally the extraction is preferred if done in a descending order along with caving. In India, regulation 104 of Coal Mines Regulations, 1957, is applied when working with seams of contagious nature.

2.1.3 ***COAL MINE REGULATION 104:***

Coal mine regulation number 104, states that for a Multi-section and contiguous workings –

(1) "No work in a higher seam or section shall be done over an area in a lower seam or section which may collapse.

(2)(a) No workings shall be made in more than one section in any seam, nor shall workings made in any two seams lying within nine metres of each other, without the prior permission in writing of the Chief Inspector and subject to such conditions as he may specify therein.

(b) Every application for permission under the sub-regulation shall be accompanied by two copies of a plan showing the proposed layout of the workings, a section of the seam or seams, the depth of the seam(s) from the surface, the rate and direction of dip, the proposed dimensions of pillars and galleries in each seam or section, and the thickness of the parting between the seams or sections.

(c) Where two or more such seams or sections are worked in a mine, the pillars in one seam or section shall as far as practicable, be vertically above or below the pillars in the other seam or section unless the strata are inclined at an angle of more than 30 degrees from the horizontal."

(d) The parting left between any two such seams or section shall not be less than three metres in thickness at any place. Provided that the Chief Inspector may, by an order in writing and subject to such conditions as he may specify therein, permit or require a smaller or greater thickness of parting, as the case may be.

2.1.4 *Indian Practices of Extraction of Pillars in Contiguous Seams*

In India, the pillars in mines having contagious seams are extracted in several ways. Basically, two techniques are used:

(i) By caving, or

(ii) With stowing.

Where contiguous seams are thick extraction with stowing is generally adopted. Where the extraction is done by caving method a parting of at least 3 m thickness has to be maintained. It may be sometimes necessary to leave some coal in order to achieve this. The coal can be left either at the floor of the top seam or at the roof of the bottom seam in such a manner so that the total thickness of the parting is not in any case less than 3 m. The pillars are extracted simultaneously if the seams lie within 9 of each other. Top to the bottom order is followed generally. If the parting is between 3-6 m, the line in both the seams must remain vertically over each other. The top seam face shall lead the bottom seam face by an amount of half a pillar distance, if parting is 6-9 m. The extraction no more needs to be simultaneous, if the parting between the seams in more than 9 m but still the extraction must be done in a descending order i.e. the upper seam should be worked out first.

When the angle of break line is known, then the optimum distance for the line of extraction in the upper seam and the line of extraction in the lower seam can be determined graphically. An example as illustrated in figure below is shown. The figure has two contiguous seams A and B. in the bottom seam the line of goaf is considered to be at y. the breakage that takes place as a result of caving is at line yy'. So for safe extraction of seam A the line of extraction should be beyond y'. The line is taken at X after taking in account the span of hold up in seam A that allows for unforeseen reasons. The distance hence formed by XY should be around 10-15 m. So the line of extraction in seam A shall lead the line of extraction in seam B by this distance.

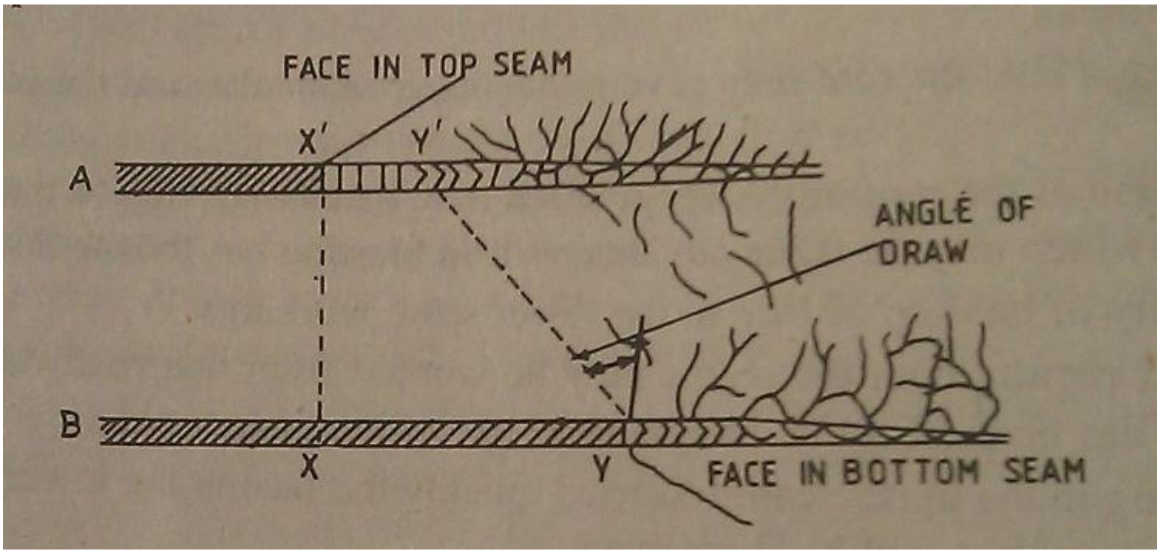


Figure 1 Angle of Draw and face lag between the two seams

In certain situations the mining in upper seam may cause undesirable undermining in the lower seam. The figure below shows this condition as an example. There are two steeply inclined seams A and B. working in seam A at XX' may cause a break along the line X'Y. This line cuts the seam B at Y. So the part of the seam B lying above Y may get undermined. As a solution the sequence of mining in both the seams shall be as properly aligned so that they do not affect the stability of one another.

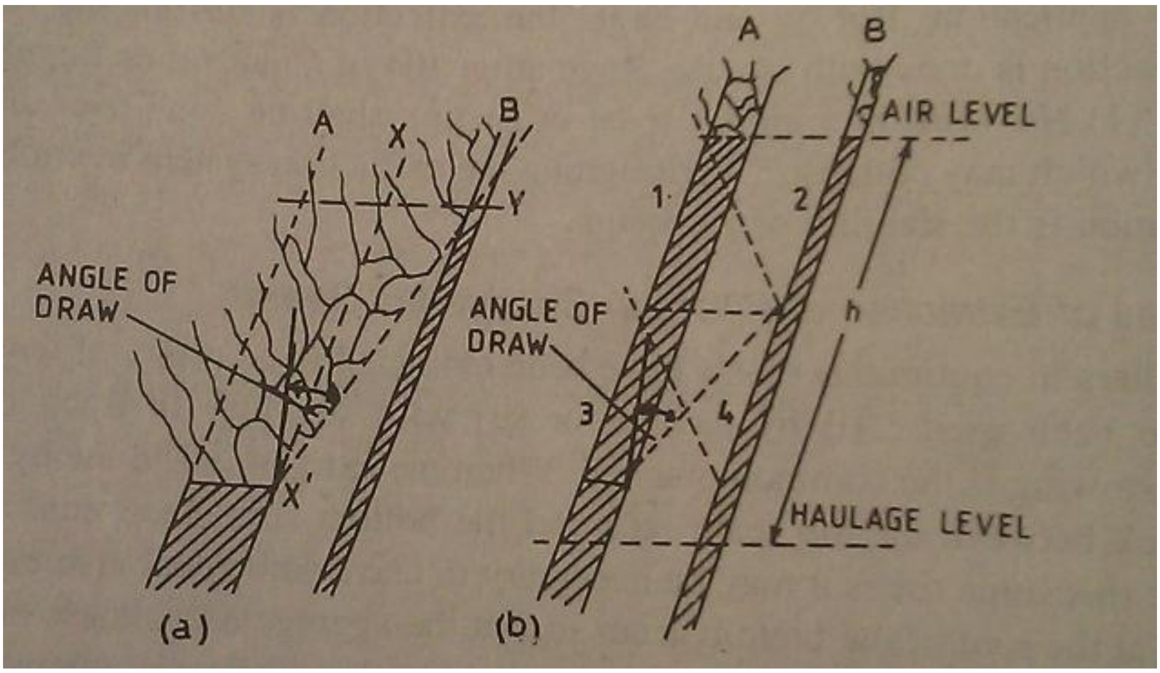


Figure 2 Angle of draw for two inclined seams

In places where the pillars are to be extracted in conjunction with stowing, a greater flexibility is available in order of extraction of different seams. However, if there are two thick seams contiguous to one another, then partial extraction with stowing of the lower seam first is preferred. Then extraction in the upper seam is carried out with full stowing or by caving in the upper slice to a maximum allowed height of 4.8m.

2.1.5 *Case studies*

2.1.5.1 Seam XIII and seam XIV, Jharia coalfields

Board and Pillar method was used at a colliery in the Jharia coalfield, XIII seam of 6.6 m thickness and XIV seam of 8 m thickness with a parting of 1.5 m between them. The depth of the cover was of 167.6 m. The XIII seam was developed along the floor. About 0.9 m of coal was left at the floor as inferior coal.

The width of the galleries was 3.6 m and height of galleries was 2.6 m. The pillars of the mine were kept of dimensions 25.5 m x 25.5 m. The XIV seam was developed in the same manner as XIII seam but along the roof. As per the legislation the pillars of seam XIV were kept vertically above the pillars of seam XIII. The pillars in the seam XIII were splitted and stowed with sand leaving stooks of dimensions 7.5 m x7.5 m. the sand was emplaced hydraulically. This operation was done in two lifts. Above the pillars of seam XIII after stowing, the pillars of seam XIV were then splitted and stowed with sand in the bottom lifts. Then the 4.8 m section along the roof was totally extracted. The order of extraction can be illustrated in the figures shown below.

Another variant method was applied. In this method, the top 3.6 m section was extracted with caving. The stooks were then extracted in slices. This was done in such a manner that the exposed roof did not ever exceed 90 m^2. However, this method did not give the desired result.

The following percentage extractions were obtained in seams XIII and XIV using the above discussed method:

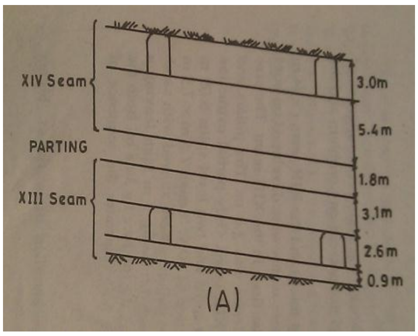
% of extraction in the XIII seam	**50%**
% of extraction in the XIV seam where stowing was applied with full top 4.8 m coal extraction	**65%**

% of extraction in the XIV seam where caving was
applied with top 3.6 m extraction **60%**

Wooden props and chocks were used as support for the faces. The average consumption of timber was about 8.49 m^3/1,000 tonnes. There was no problem posed by strata. The subsidence of the surface was observed to be between 5.48 and 16.45 cm.

2.1.5.2 Seam XIV and Seam XIII, Jharia collieries

Similarly at one other colliery in Jharia coalfield the XIV seam of 8.8 m thickness and the XIII seam of 5.94 in thickness occurred contiguously with a parting between them of about 1.5-1.8 m thickness. These were developed using bord and pillar method of extraction. The seam XIV was developed along the roof while the seam XIII was developed along the floor. The centre to centre size of pillars was 30.5 m while the width of galleries was 3.6 m. As per regulation, the pillars and galleries in the XIV seam were vertically above the pillars in the XIII seam. After the work of development, two rise to dip splits and two level splits were driven in each pillar. The dimension of these splits was 6.09 m wide x 4.5 m high. This gave an extraction of 60%. Stooks were left in goaf along with some coal and dimension of stooks were 7.5 m x 7.5 m. Sand was used for stowing purpose for all the galleries. The XIV seam was worked in two lifts by longwall method. Each lift was 3 m high and the parting of 2.74 m between the lifts was left. The face in the bottom seam was leading the face in the top seam by 30.8 m. the gobs in both the seams were stowed solid; sand was used for this purpose.



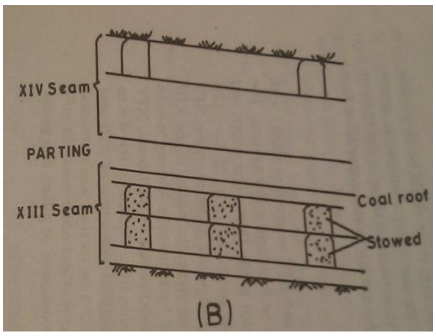


Figure 3 seam XIII and seam XIV in Jharia coalfields

2.1.5.3 RK-8 Incline, SCCL

In this mine name, RK-8 Incline, there were five seams. These were #2A seam, #2 seam, #3 seam, #4 seam and #5 seam. Inferior quality of coal was found in #2A seam after development of two pillars and hence it was left virgin. Development and depillaring was carried out in #2 seam, #3 seam and #4 seam. The #5 seam was left virgin below them earlier. Already worked out and depillared workings of #3 seam and #4 seam overlay the #5 seam. The parting between #2 seam and #3 seam, #3 seam and #4 seam, #4 seam and #5 seam are 37 m, 10 m and 7-9 m respectively.

The seam 5 was then later on proposed to be developed at north side under the already developed seams 3 & 4 in the panel #ST1. Also the three seams were to be depillared simultaneously. This was an experimental trial under the Science and Technology project which was approved by Ministry of Coal. Several advantages as concentrated working along with increased production and productivity and efficiency were intended at the time of conception of the project. Moreover the waiting time for development can be avoided which otherwise would have to be till the goafs in the seam 3 and 4 which overlay seam 5 settles down completely.

Since the development permission taken earlier was for contiguous workings hence there remained several major issues regarding the superposition of the pillars which was maintained in #3 seam and #4 seam. To take care of any unavoidable circumstances the superposition of the pillars were selected in a small sized panel for the trial purpose, near the boundary of the leasehold area. There was maintained a half pillar lag in the line of extraction of seams #3, #4 and #5 successively in the underlying working. This was done to maintain coincidence of faces. Continuous monitoring was applied. This helped in quantifying the data for adverse condition. And since it was an experimental trial, the working could be suitably modified or abandoned as per requirements without much loss in coal as the upper seams can still be worked with conventional methods any time.

Since the corner of the property was chosen for this experimental so any failure if occurs will not effect the rest of the property.

Followings conclusion could be drawn from this working:

- Lack of knowledge in the field of contiguous seam mining has led to loss of coal.
- There were no proper guidelines for accessing the stability of parting. Similarly there was lack of guidelines for design purpose of multiple seams.
- The support design was based on empirical guidelines only.
- Strata control in contiguous seams mining was much easier as the line of extraction in the upper seam matches with the line of extraction in a single seam.
- The miscellaneous expenditure incurred for pumping, power, manpower, tramming etc. can be saved if simultaneous extraction is applied.
- The amount of saving that was obtained by this experimental trial was about Rs. 30/te of coal produced.

2.2 NUMERICAL MODELLING:

2.2.1 Overview

FLAC stands for Fast Lagrangian Analysis of Continua. It is a program developed for engineering mechanics computation. It basically is an explicit finite difference program in two dimensions. Materials may undergo plastic flow on attaining their yield limits, this program simulates such situation and materials behaviour of structures built of soil, rock or other materials. Materials are here in represented by respective zones. These grids are adjusted by the user of the program to suit the shape of the object to be studied. The elements of the material behave as per a set of laws (linear/non linear). Their behaviour is guided by the boundary conditions given by the user. The material may depend on the condition yield or flow. The grids can similarly deform and move along with the materials as they represent in the model (observed in large strain conditions). *FLAC* uses an explicit, Lagrangian calculation scheme and the mixed-discretization zoning technique. This ensures that the models represented flow and collapse very accurately. The program also does not require large memory usage as no matrices are formed. Automatic inertia scaling and automatic damping are used that do not have any influence on the mode of failure. This is done to overcome the drawbacks posed by explicit formulation (i.e., small time step limitation and the question of required damping).

2.2.2 Features available in FLAC:

FLAC was originally developed for geotechnical and mining engineers. It incorporates a wide range of capabilities that can be used to solve complex mechanics problems even in other fields. It has many built in models that allows for the simulation of highly nonlinear, irreversible response representation of geological or similar materials available. FLAC has many other features, some of which can be enumerated as below:

- Interface elements to simulate distinct planes along which slip and/or separation can occur;
- Plane-strain, plane-stress and axisymmetric geometry modes;
- Groundwater and consolidation (fully coupled) models with automatic phreatic surface calculation;
- Structural element models to simulate structural support (e.g., tunnel liners, rock bolts, or foundation piles);
- Extensive facility for generating plots of virtually any problem variable;
- Optional dynamic analysis capability;
- Optional viscoelastic and viscoplastic (creep) models;
- Optional thermal (and thermal coupling to mechanical stress and pore pressure) modelling capability;
- Optional two-phase flow model to simulate the flow of two immiscible fluids (e.g., water and gas) through a porous medium; and

FLAC can be operated by the user as either a *menu-driven* or a *command-driven* program. The menu driven program allows the user to simulate in response to point-and-click operations. No other input method is required in this mode. While the command driven mode requires the user to have acquaintance with the commands used in FLAC. This may be a little difficult bust has several advantages. They can be enumerated as:

1) Recognizable word commands are used when command mode is used. This allows the user to identify the application of each command easily and also in a logical manner.
2) Generally engineering simulation are too lengthy sequential operations. A series of input commands can match the original sequence being followed in the problem.

3) A text editor can be used to modify a FLAC data file and this also helps in keeping up the records.
4) The data file can be produced at the end of the project as an appendix and hence can serve for the purpose of authenticity.
5) This helps us in pre development and post alteration in the program as per requirement.

2.2.3 Comparison with Other Methods:

FLAC and other more common methods both use a set of differential equation. These equations are used into matrices of equations for each and every element. These relate displacement at nodes to forces at respective node. FLAC derives the equations by the finite difference method still the equations match very much to those derived from finite element method. But the differences can still be enumerated as below:

1. For accurate simulation of plastic flow or plastic collapse mixed discretization technique is used. This is assumed to be more comparable to physical reality as compared to reduced integration method used by other finite element programs.
2. Even if the elements are essentially static, still full dynamic equations of motion are used. This helps to track processes that are physically unstable to be tracked and followed without much of numerical distress.
3. FLAC uses an explicit solution scheme for solving the problems. It has an advantage over implicit technique used in other programs. This technique can solve any arbitrary non linearity encountered in stress/strain laws in the problem in same computer time as it does for linear laws. Had it been using implicit technique the time consumed would have been much more.
4. In FLAC it is not important to save any matrices. This helps in two ways
    a. Large models can be solved without much requirement of memory.
    b. A large strain simulation consumes about the equal time as consumed by the small strain problem. The reason being that no stiffness requires to be updated in this case.
5. FLAC is a robust programming model. It can handle any constitutive model. It does not include any adjustment in the solution algorithm.
6. FLAC uses row and column fashion to number its element rather than sequential fashion used by many other finite element programs. This helps in identifying the

element under consideration when specifying input or even at the time of interpretation of output.

Still there are three major drawbacks of FLAC, which can be marked out as:

- Linear simulation problems take longer time with FLAC than they would have taken with other finite elements models. FLAC is best when applied to non linear problems or problems in which instability may occur.
- The solution time taken by FLAC depends on the ratio of the longest natural period to the ratio of the shortest natural period taken by the system that is being considered or modelled.
- Certain problems are very inefficient to model, e.g. beams, or solutions of situations that contain very large disparities in element size or elastic moduli.

2.2.4 Recommended steps for numerical modelling:

The steps recommended for solving a real life situation can be enlisted as below:

Step 1	Define the objectives for the model analysis
Step 2	Create a conceptual picture of the physical system
Step 3	Construct and run simple idealized models
Step 4	Assemble problem-specific data
Step 5	Prepare a series of detailed model runs
Step 6	Perform the model calculations
Step 7	Present results for interpretation

Step 1: Define the Objectives for the Model Analysis

The purpose of analysis generally constrains the level of details to be considered. Only crude model may be simulated if the purpose is just to decide between two conflicting mechanisms provided it allows the mechanisms to occur. Since there are many complex situations in the real life, it seems tempting to include all of them, but still they shall be omitted if they are likely to have any influence on the property being studied or they are just irrelevant to it. The objective should be to start with a global view and refine as far as possible and if required.

Step 2: Create a Conceptual Picture of the Physical System

At the beginning the user shall have the conceptual picture of the problem. It is necessary to have an initial estimate of the expected behaviour of the model under the imposed conditions. For this purpose a questionnaire shall be prepared. It shall have the questions as :

- Would the system be stable?
- Is the predominant response linear or non linear?
- Are we expecting large or small movements with the sizes of objects within the problem region?
- Are there any discontinuities that may be affecting the simulation and are they well defined?
- Can groundwater have influence on the situation?
- Does the boundaries o the system extend to infinities or are they well defined?

Such characteristic control the gross characteristics of the numerical model. This may include design of the model geometry, the types of material models, the boundary conditions, and the initial equilibrium state for the analysis. Then the user needs to determine whether a 3D model is needed or may the geometric similarities can constrain the model to a 2D problem.

Step 3: Construct and Run Simple Idealized Models

It is a better thought to run and test a basic simple and idealized model first than to go for computing the full program of the detailed model. In a project simple model shall be crated and tested at the earliest possible stage. This helps in both generating data and understanding the situation. It may be required to repeat the step 2 after running the simple model. Such basic models help in revealing the shortcomings of the programs and also help in finding oput remedies. Once the shortcomings are overtaken they wont appear in the detailed program. Such models also help us to determine which parameter has the maximum effect on the result being generated.

Step 4: Assemble Problem-Specific Data

The types of data required for a model analysis include:

1) Details of the geometry of the model being considered.
2) Basic locations of geologic structures situated near or within the boundary conditions (e.g., faults, joint sets, bedding planes)

3) Behaviour of the material under consideration (e.g., elastic/plastic properties, post-failure behaviour)
4) initial conditions and boundary conditions (e.g., pore pressures, in-situ state of stress, saturation); and
5) Factors of external loading (e.g., pressurized cavern, explosive loading).

Step 5: Prepare a Series of Detailed Model Runs

Several points should be considered while preparing a set of model runs for calculation. They are listed below:

1. It may be difficult to obtain sufficient information to arrive at a useful conclusion if the runtime of the simulated model is too large. Parameter variation can be done on multiple computers to shorten the computation time.
2. The model being simulated shall be saved at several intermediate stages rather than just once at last. This will help in avoiding rerunning the same program again and again from the beginning to consider just one parameter variation. And change in parameter can continue from the stage required.
3. The amount of disk space for saving the file shall be considered.
4. There should always be sufficient number of monitoring locations in the model. This provides a clear interpretation of model results and enables for comparison with physical data. Several points in the model should be located where of the change of a parameter (such as velocity or stress, displacement) can be monitored during the calculation. To check equilibrium or failure state at each stage of an analysis, the maximum unbalance force in the model should be continuously monitored.

Step 6: Perform the Model Calculations

The model shall be split in several separate sections and run before starting a series of complete run. This ensures that the response of the simulation is as expected and there is no error in the program. Once it is checked then the user can link several small sequences and run the whole program in one go. It would also be possible then to interrupt the calculation at any time during a sequence of runs. It will also help in viewing result and modifying parameters as per requirement.

Step 7: Present Results for Interpretation

In the final stage the result shall be presented and a clear interpretation of the result shall be made. It is best to have a graphical presentation as the changing parameter and the effect in the output. The output shall be so presented as to compare directly to field measurements and observations. The plots should always show the locations of interest such as locations of calculated stress concentrations, or areas of stable movement versus unstable movement in the model. Also the numerical values shall be readily available with the user to compare with the field observed data and hence better interpretation. The chart below describes the steps to be implemented by the modeller to reach the final output and better interpretation of results:

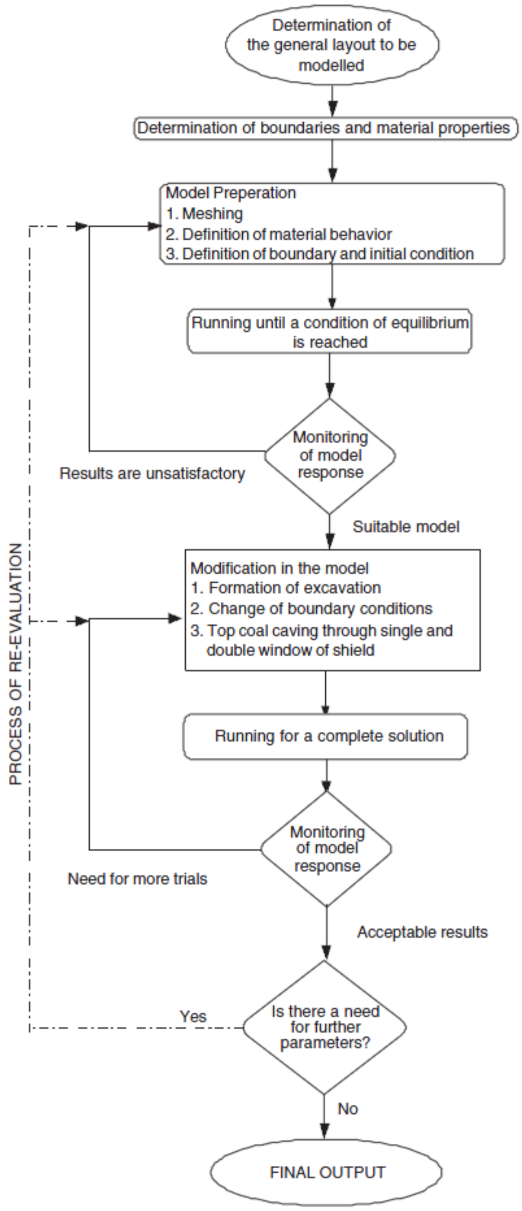


Figure 4 A general flowsheet of modelling procedure (Yasitli, 2002; Unver and Yasitli, 2002; Itasca, 1997)

CHAPTER 3

METHODOLOGY

- *PARAMETERS OF NUMERICAL MODEL*
- *NUMERICAL MODEL PROGRAM (A SAMPLE)*
- *SEQUENCE OF THE PILLAR AND EXCAVATIONS WERE SIMULATED FOR CONSIDERED PARAMETERS*

3.1 METHODOLOGY

3.1.1 PARAMETERS OF NUMERICAL MODEL

This numerical modelling situation includes contiguous mining of two seams of coal. It shows different stages of a depillaring process. Both the seams were excavated to their full thickness. The different stages include division of pillars, splitting, and extraction of the stooks so formed leaving just ribs in the goafs. For simulation two seams of coal 3m thick each were selected. For idealised condition four galleries in each seam were driven. As per CMR, 1957 the pillar of the top seam must be vertically above the pillars of the bottom seam. Sot such condition was selected. For ease of study and for better understanding of the effect few parameters of the model were kept constant in both the seams. These include:

Width of the pillars	-	20.2 m
Width of development gallery	-	4.8 m
Width of split gallery	-	5 m
Width of ribs	-	2.5 m
Height of galleries	-	3 m

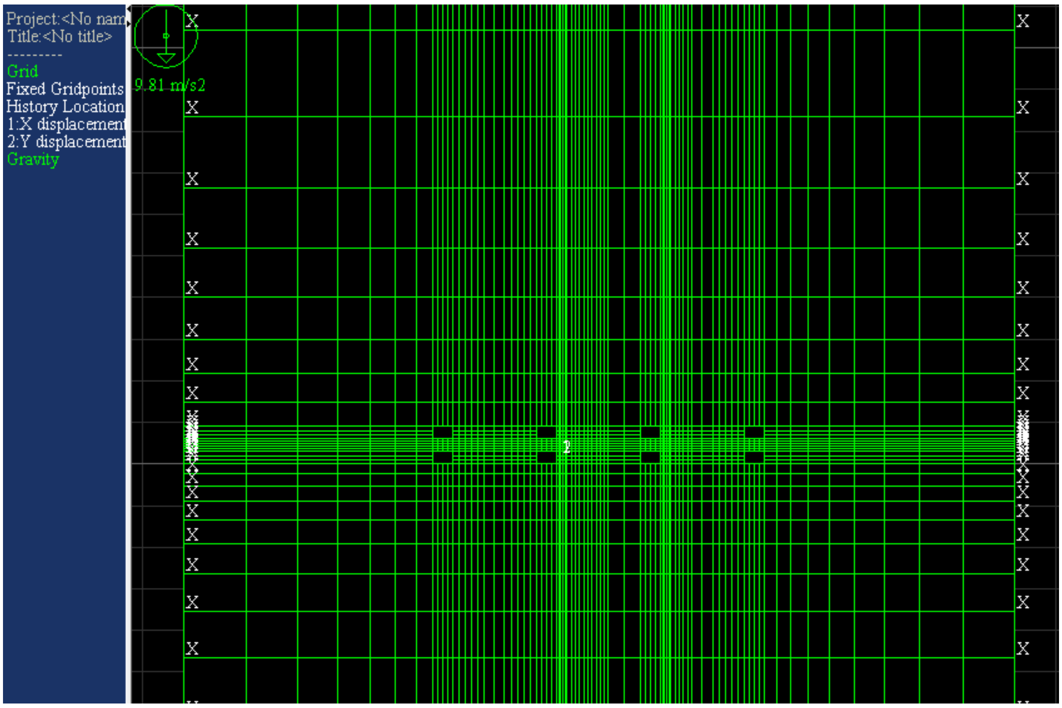


Figure 5 Grid elements of the model with two seams and 3 pillars with parting thickness of 3 m and depth cover of 150 m

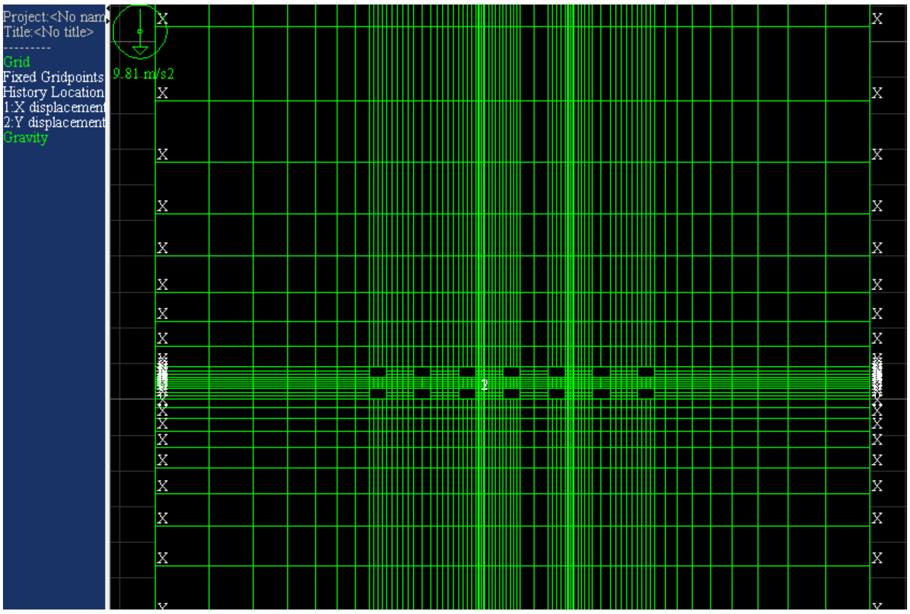


Figure 6 Grid elements of the model with two seams and 3 pillars with parting thickness of 3 m and depth cover of 150 m after splitting of galleries

The pillar size considered in the model was 25 m. This size is in accordance with the field experimental trials. After the generation of development model in first stage the pillars were given splits of 5 m and effects were studied. In later stages both the seams were extracted upto 3 m height. Ribs were left in both the goafs. Numerical modelling was then used to study the stress conditions in the pillars in development stage, in stooks, ribs and partings in both the seams.

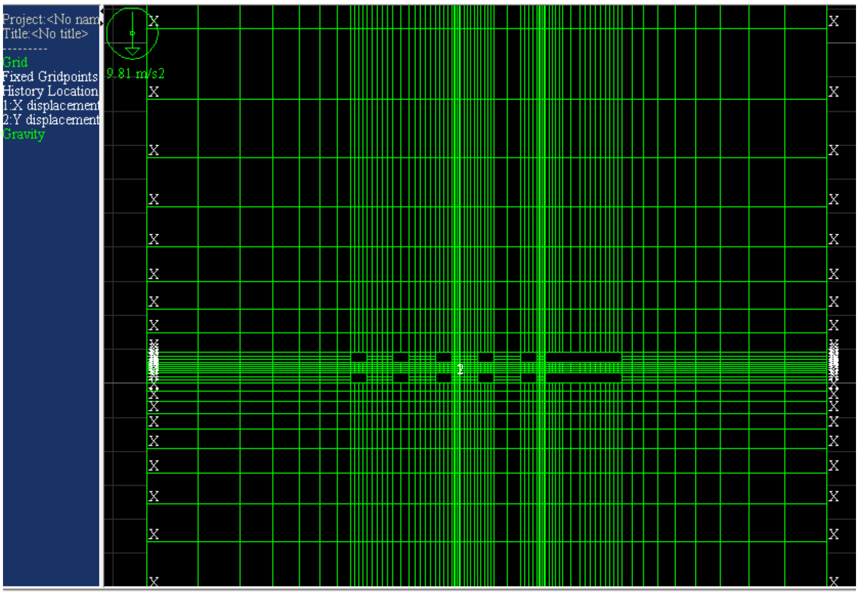


Figure 7 Grid elements of the model with two seams and 3 pillars with parting thickness of 3 m and depth cover of 150 m after excavation of one pillar

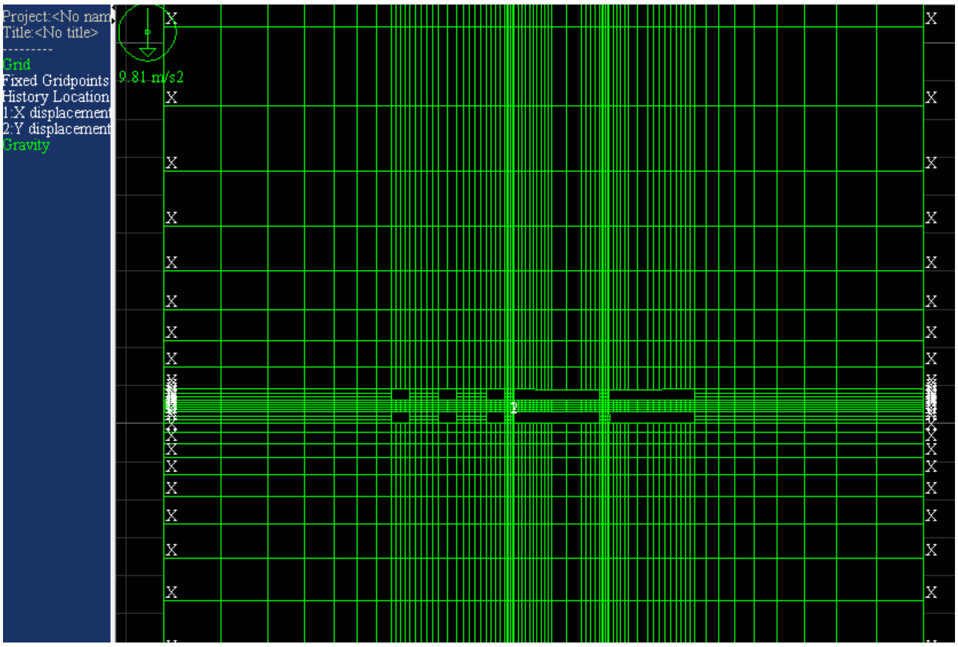


Figure 8 Grid elements of the model with two seams and 3 pillars with parting thickness of 3 m and depth cover of 150 m after excavation of two pillars

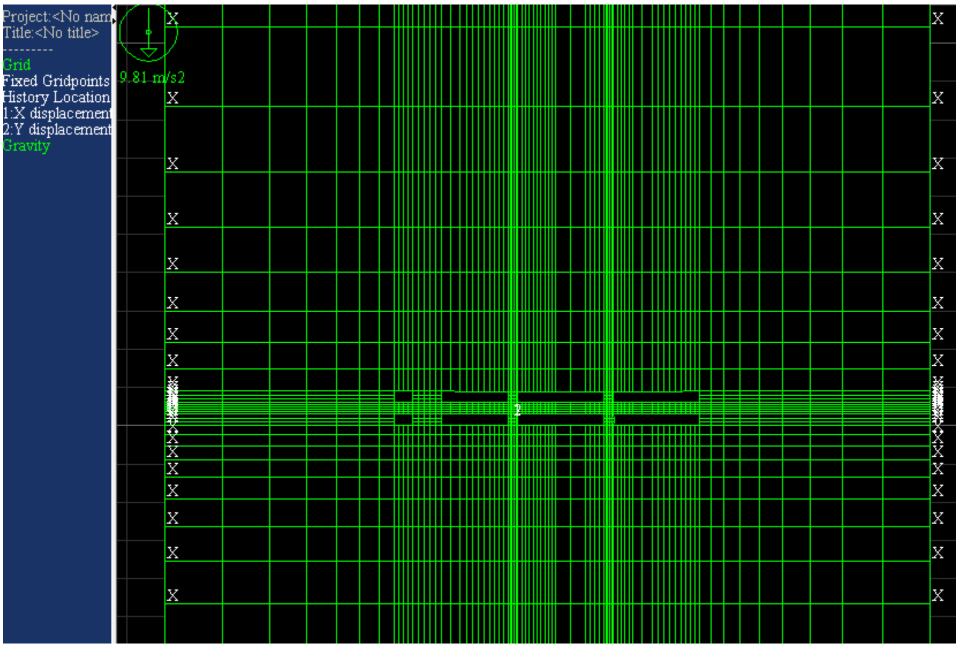


Figure 9 Grid elements of the model with two seams and 3 pillars with parting thickness of 3 m and depth cover of 150 m after excavation of two and a half pillars with two ribs

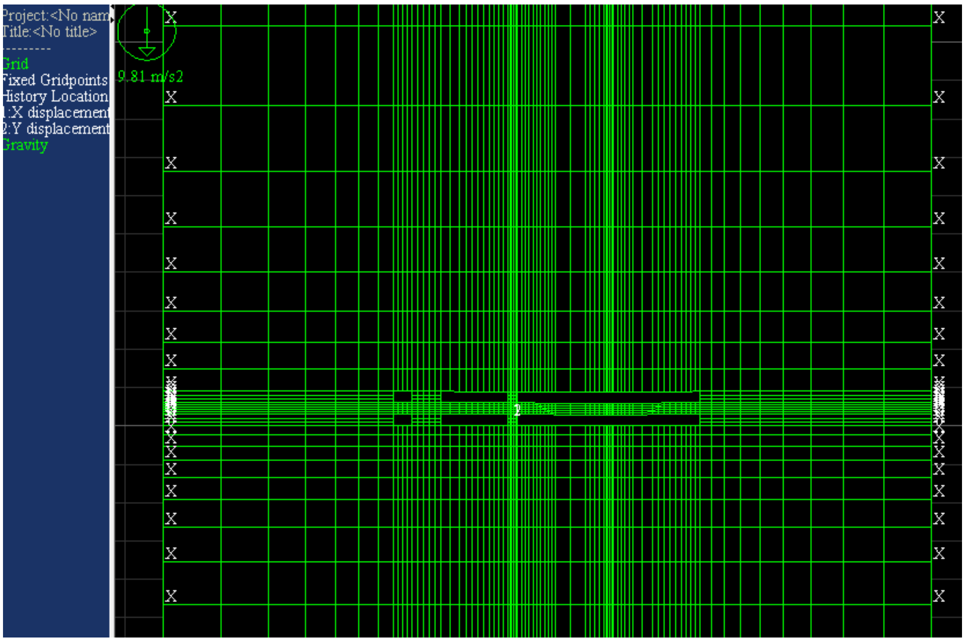


Figure 10 Grid elements of the model with two seams and 3 pillars with parting thickness of 3 m and depth cover of 150 m after excavation of two and a half pillars with one rib

About 20 different conditions of parameters were generated and studied for different stress behaviours. The parameters were changed at regular intervals to get a better idea of the behaviour of the model. The parameters that were varied in the study were:

Parting between the seams : 3-9 m, the interval between variations was 2 m

Depth of the cover : 150-750 m, the interval between the variations was set at 150 m.

3.1.2 THE SEQUENCE OF SIMULATION OF PILLARS IN DEVELOPMENT STAGE AND IN EXCAVATION STAGE WAS:

Step 1	development stage, pillars and galleries were developed in both the seams.
Step 2	providing splits in both the seams in two rows of pillars
Step 3	the row pillars in both the seams are extracted with a single rib left inside the goaf.
Step 4	two row pillars are extracted in both the seams with two ribs left inside goaf in each seam.

Step 5	two and a half row pillars are extracted with two ribs left in each seam inside the goaf.
Step 6	two and a half pillars are extracted with a single rib left in each seam in the goaf.

3.1.3 Assumption in the model:

The elements in the panel considered are small. The elements are of size 0.5 m in the ribs and 1 m in the pillar. The maximum size represented by each of them is 2 m^2. The dimensions of mesh elements increase geometrically from the inner model to the outer boundary. This is done so as to reduce the simulation and computation time. The problem under study has approximate boundary condition and grid pattern for varying depth cover. The depth cover varies from 150 m to 750 m. the development model is then turned into an excavation model. The conditions applied are plain strain condition and Mohr Coulomb criteria are used. The Sandstone element was used as the depth covers the floor material and parting. The Young's modulus and the Poisson's ration for sandstone were 5 GPa and 0.25 respectively. The properties of the Coal considered are enlisted as below:

Young's modulus	2 GPa,
Poisson's ratio	0.25,
Cohesion	2.5 MPa,
Density	1.4 g/cm^3,
Tensile Strength	1.8 MPa, and
Angle of internal friction	30^o

The top of the model is left free to move in any direction. The edge of the model in bottom is constrained in moving in y direction that is vertically. The boundary conditions applied in the bottom edge is of roller type, i.e. the body can move in horizontal direction but not up and down.

Since there were no in situ stress data available so with the help of following equations the in situ stresses were calculated:

$$\text{Vertical stress} = \rho \times H$$

$$\text{Horizontal stress} = 3.75 + 0.015\,H$$

Where,

ρ = specific weight of the overlying rock mass and

H = depth cover

The gravity also gives an effect of graduated stress. The model run for generating the in-situ stresses, before adding the mine openings or galleries to the simulation. The displacements after this pre-run are reset to zero. Then the mine opening or galleries required are added to the model. After this the simulation is re-run. This gives the final stress distribution.

CHAPTER 4

RESULTS AND ANALYSIS

- MAXIMUM STRESS GENERATED OVER PILLARS (AFTER DEVELOPMENT), STOOKS AND RIBS (AFTER EXTRACTION OF TWO AND HALF PILLARS)
- PLOTS FOR THE RESULTS OBTAINED
- EXAMPLES OF THE STRESS DISTRIBUTION OF SOME TYPICAL CONDITIONS
- ANALYSIS OF THE RESULTS OBTAINED AFTER SIMULATION

RESULTS AND ANALYSIS

4.1 RESULTS

4.1.1Numerical model simulation outputs for some typical problems:

1) Stress distribution for pillars and parting after development, and stooks, ribs and parting after excavation of two and a half pillars for 3 m parting thickness and 150 m depth cover.

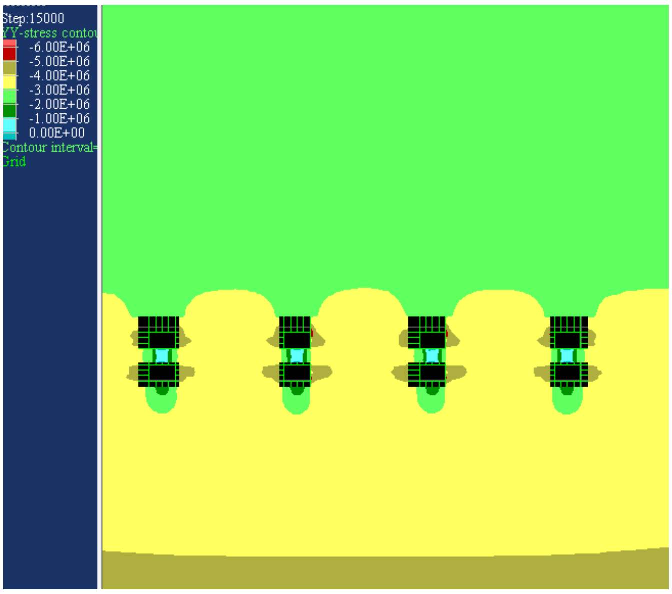


Figure 11 Stress distributions in pillars and parting after development for parting thickness of 3 m and depth cover of 150 m

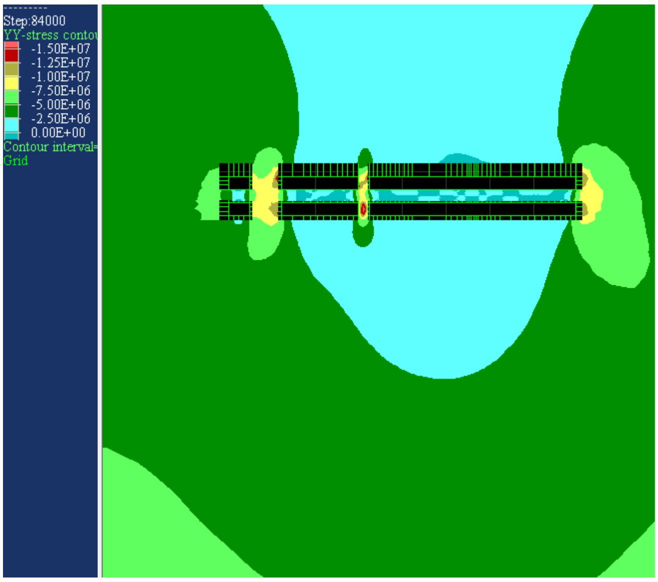


Figure 11Stress distribution in stook, rib and parting after excavation of two and a half pillars for a parting thickness of 3 m and depth 150 m

2) Stress distribution for pillars and parting after development, and stooks, ribs and parting after excavation of two and a half pillars for 5 m parting thickness and 450 m depth cover.

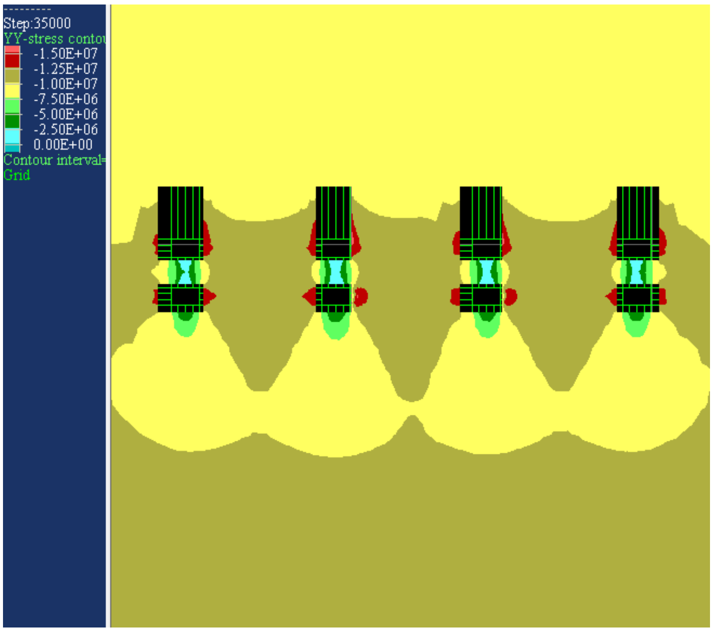


Figure 12 Stress distributions in pillars for 5 m parting and 450 m depth cover at development stage

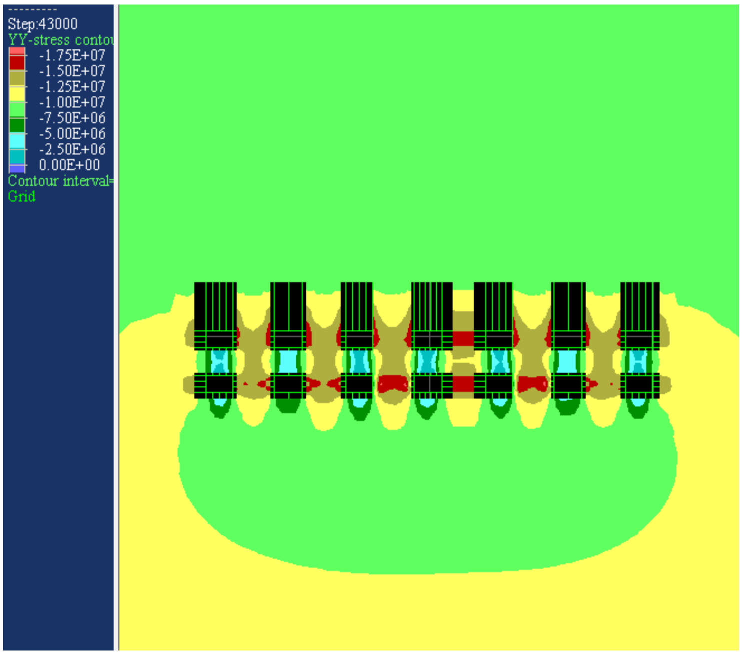


Figure 13 Stress distributions in splits for 5 m parting and 450 m depth cover after splitting of pillars

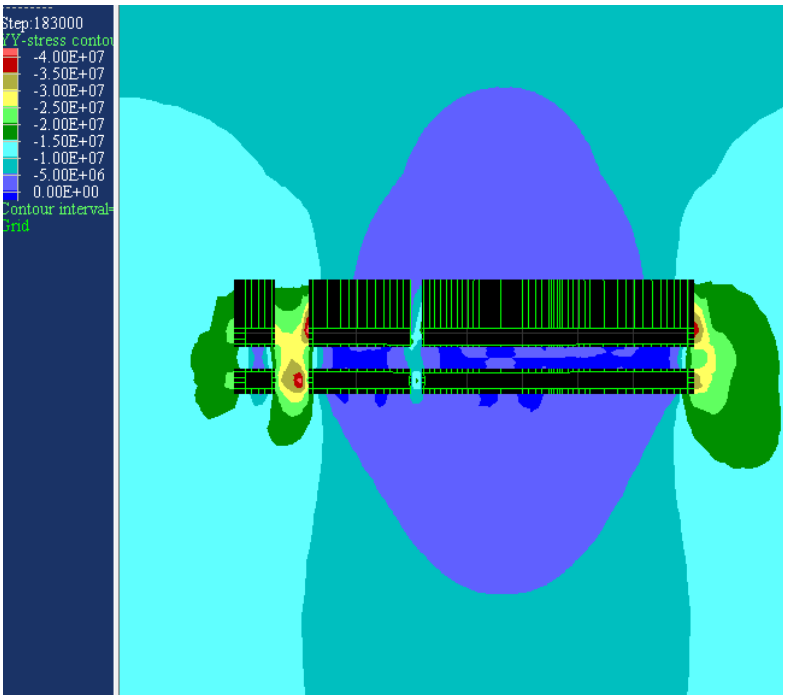


Figure 14 Stress distributions in stook, rib and pillar and parting for 5 m parting and 450 m depth cover after excavation of two and half pillars

3) Stress distribution for pillars and parting after development, and stooks, ribs and parting after excavation of two and a half pillars for 3 m parting thickness and 150 m depth cover.

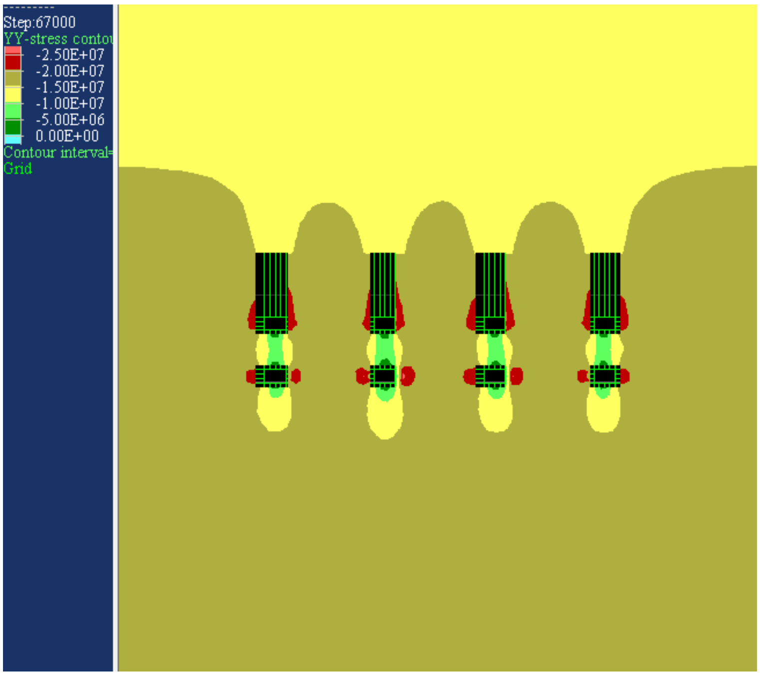


Figure 15 Stress distributions in pillar and parting for 9 m parting and 750 m depth cover after development stage.

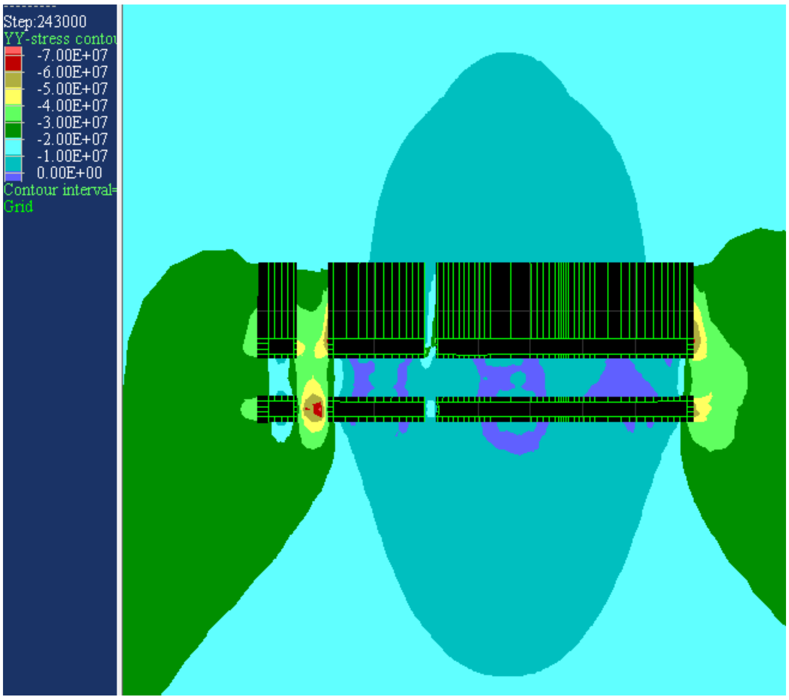


Figure 16 Stress distributions in stook, rib and parting for 9 m parting and 750 m depth cover after excavation of two and half pillars

4.2 Maximum stress over pillar (after development), stook and rib (after extraction of two and half pillars) obtained after simulation program was run:

Table 1 Maximum Stress in the pillars, stooks ribs and partings for different parting thickness at 150 m of depth cover

Depth (m)	Parting (m)	Seam	Stress in pillar	Stress in stook	Stress in Rib	Stress in parting in development stage	Stress in parting after excavation
150	3	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		
	5	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		
	7	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		
	9	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		

Table 2 Maximum Stress in the pillars, stooks ribs and partings for different parting thickness at 300 m of depth cover

Depth (m)	Parting (m)	Seam	Stress in pillar	Stress in stook	Stress in Rib	Stress in parting in development stage	Stress in parting after excavation
300	3	Top	10	30	17.5	5	7.5
		Bottom	9	27.5	17.5		
	5	Top	10	30	17.5	5	12.5
		Bottom	9	27.5	17.5		
	7	Top	10	27.5	17.5	5	12.5
		Bottom	9	27.5	17.5		
	9	Top	11	25	22.5	5	12.5
		Bottom	11	25	17.5		

Table 3 Maximum Stress in the pillars, stooks ribs and partings for different parting thickness at 450 m of depth cover

Depth (m)	Parting (m)	Seam	Stress in pillar	Stress in stook	Stress in Rib	Stress in parting in development stage	Stress in parting after excavation
450	3	Top	15	40	17.5	6.25	12.5
		Bottom	13.75	40	17.5		
	5	Top	15	40	17.5	6.25	17.5
		Bottom	15	40	17.5		
	7	Top	15	40	22.5	6.25	17.5
		Bottom	15	40	17.5		
	9	Top	15	40	27.5	6.25	12.5
		Bottom	15	40	17.5		

Table 4 Maximum Stress in the pillars, stooks ribs and partings for different parting thickness at 600 m of depth cover

Depth (m)	Parting (m)	Seam	Stress in pillar	Stress in stook	Stress in Rib	Stress in parting in development stage	Stress in parting after excavation
600	3	Top	18.75	50	15	8.75	15
		Bottom	18.75	50	15		
	5	Top	20	50	15	8.75	25
		Bottom	17.5	50	15		
	7	Top	20	50	25	8.75	15
		Bottom	20	50	15		
	9	Top	21.25	50	25	11.25	25
		Bottom	21.25	50	15		

Table 5 Maximum Stress in the pillars, stooks ribs and partings for different parting thickness at 750 m of depth cover

Depth (m)	Parting (m)	Seam	Stress in pillar	Stress in stook	Stress in Rib	Stress in parting in development stage	Stress in parting after excavation
750	3	Top	22.5	50	15	12.5	25
		Bottom	22.5	50	15		
	5	Top	22.5	50	15	12.5	25
		Bottom	25	70	15		
	7	Top	25	50	15	12.5	25
		Bottom	25	70	15		
	9	Top	25	50	35	12.5	25
		Bottom	25	70	15		

Considering the variation of depth covers and keeping the partings constant. The result can be tabled as:

Table 6 Maximum stress distribution with different depth at constant parting thickness

Parting (m)	Depth (m)	Seam	Stress in pillar	Stress in stook	Stress in Rib	Stress in parting in development stage	Stress in parting after excavation
3	150	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		
	300	Top	10	30	17.5	5	7.5
		Bottom	9	27.5	17.5		
	450	Top	15	40	17.5	6.25	12.5
		Bottom	13.75	40	17.5		
	600	Top	18.75	50	15	8.75	15
		Bottom	18.75	50	15		
	750	Top	22.5	50	15	12.5	25
		Bottom	22.5	50	15		
5	150	Top	5.5	13.75	13.75	2.5	6.25

		Bottom	5.5	13.75	15		
	300	Top	10	30	17.5	5	12.5
		Bottom	9	27.5	17.5		
	450	Top	15	40	17.5	6.25	17.5
		Bottom	15	40	17.5		
	600	Top	20	50	15	8.75	25
		Bottom	17.5	50	15		
	750	Top	22.5	50	15	12.5	25
		Bottom	28	70	15		
7	150	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		
	300	Top	10	27.5	17.5	5	12.5
		Bottom	9	27.5	17.5		
	450	Top	15	40	22.5	6.25	17.5
		Bottom	15	40	17.5		
	600	Top	20	50	25	8.75	15
		Bottom	20	50	15		
	750	Top	25	50	15	12.5	25
		Bottom	25	70	15		
9	150	Top	5.5	13.75	13.75	2.5	6.25
		Bottom	5.5	13.75	15		
	300	Top	11	25	25.5	5	12.5
		Bottom	11	25	17.5		
	450	Top	15	40	27.5	6.25	17.5
		Bottom	15	40	17.5		
	600	Top	21.25	50	25	11.25	25
		Bottom	21.25	50	15		
	750	Top	25	50	35	12.5	25
		Bottom	25	70	15		

Table 7 Depth verses maximum stress in pillars at different parting distances in top seam

Depth	Max Stress in pillar at 3 m parting	Max Stress in pillar at 5 m parting	Max Stress in pillar at 7 m parting	Max Stress in pillar at 9 m parting
150	5.5	5.5	5.5	5.5
300	10	10	10	11
450	13.75	15	15	15
600	18.75	20	20	21.25
750	22.5	22.5	25	25

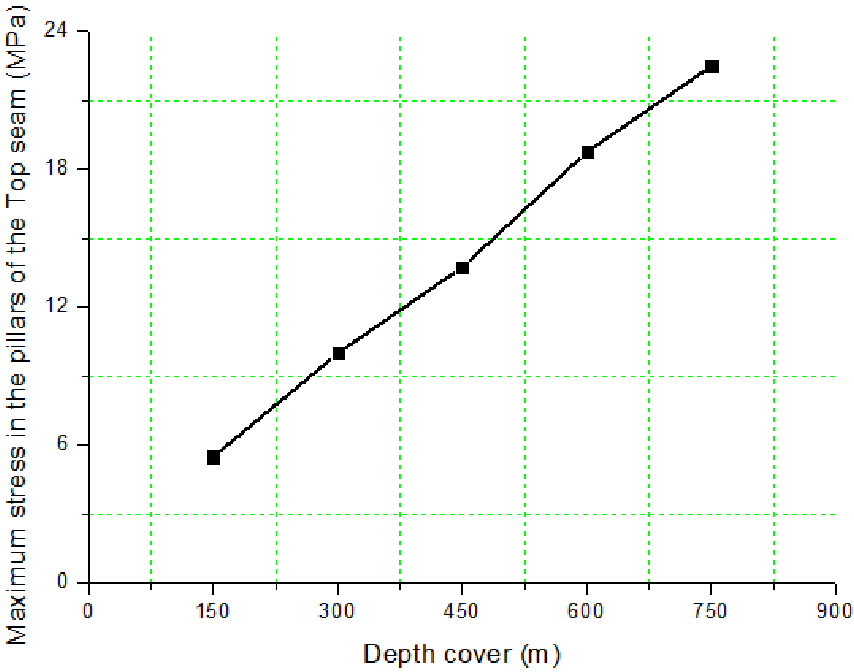


Figure 17 Depth verses stress on pillar of the top seam for parting thickness 3 m

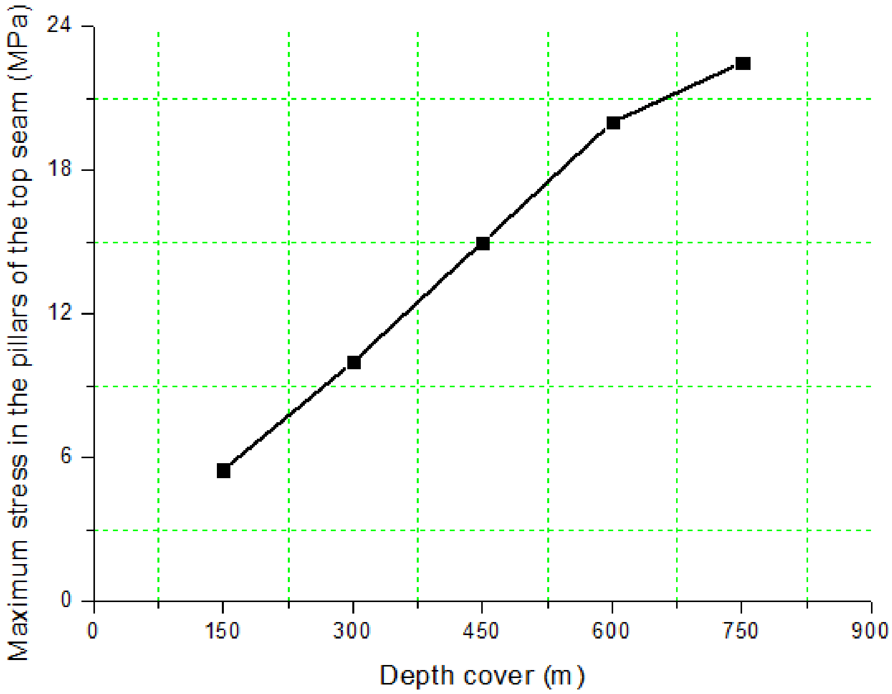


Figure 18 Depth verses stress on pillar of the top seam for parting thickness 5 m

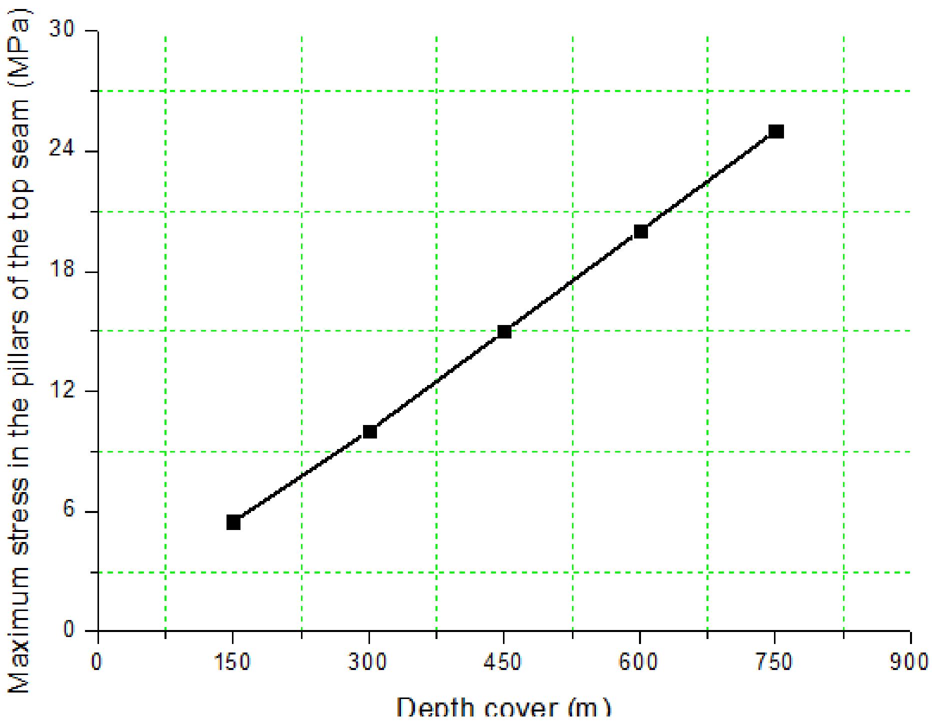


Figure 19 Depth verses stress on pillar of the top seam for parting thickness 7 m

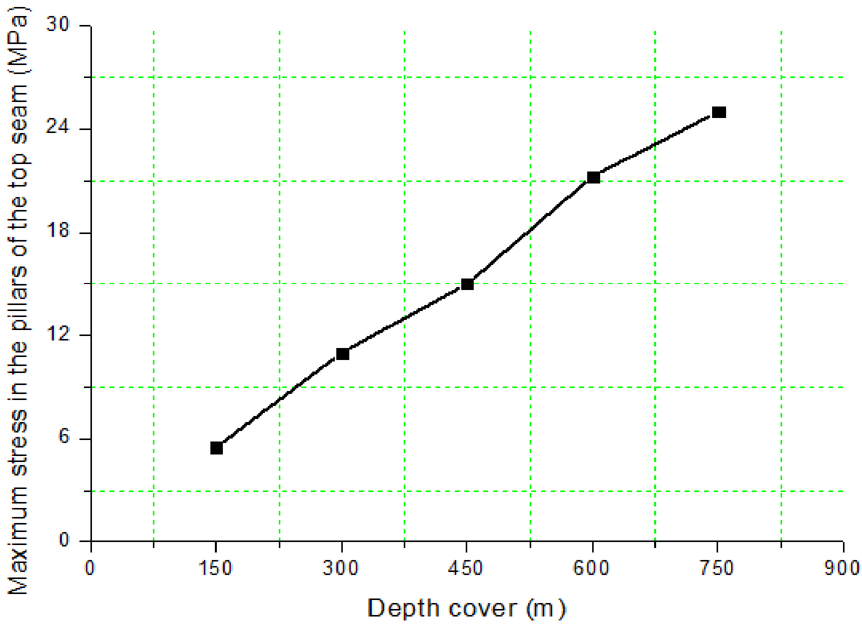


Figure 20 Depth verses stress on pillar of the top seam for parting thickness 9 m

Table 8 Depth verses maximum stress in pillars at different parting thickness in bottom seam

Depth	Max Stress in pillar at 3 m parting	Max Stress in pillar at 5 m parting	Max Stress in pillar at 7 m parting	Max Stress in pillar at 9 m parting
150	5.5	5.5	5.5	5.5
300	9	9	9	11
450	13.75	15	15	15
600	18.75	17.5	20	21.25
750	22.5	28	25	25

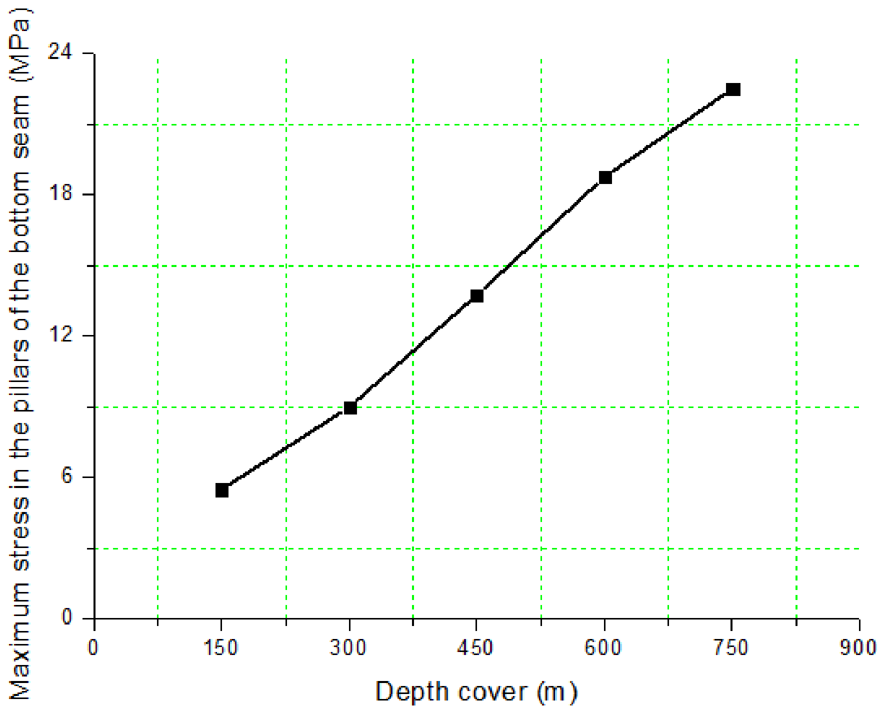


Figure 21 Depth verses stress on pillar of the bottom seam for parting thickness 3 m

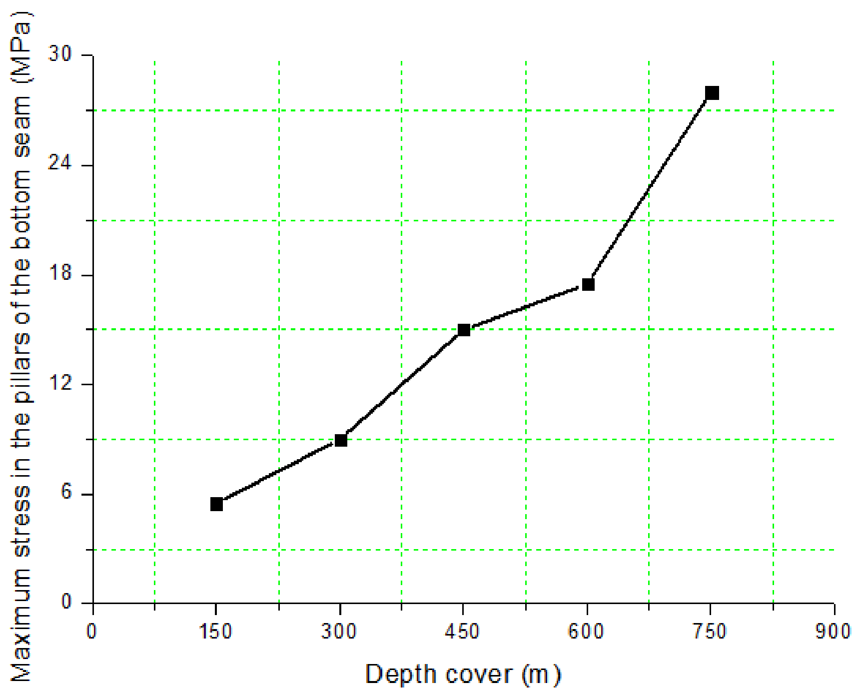


Figure 22 Depth verses stress on pillar of the bottom seam for parting thickness 5 m

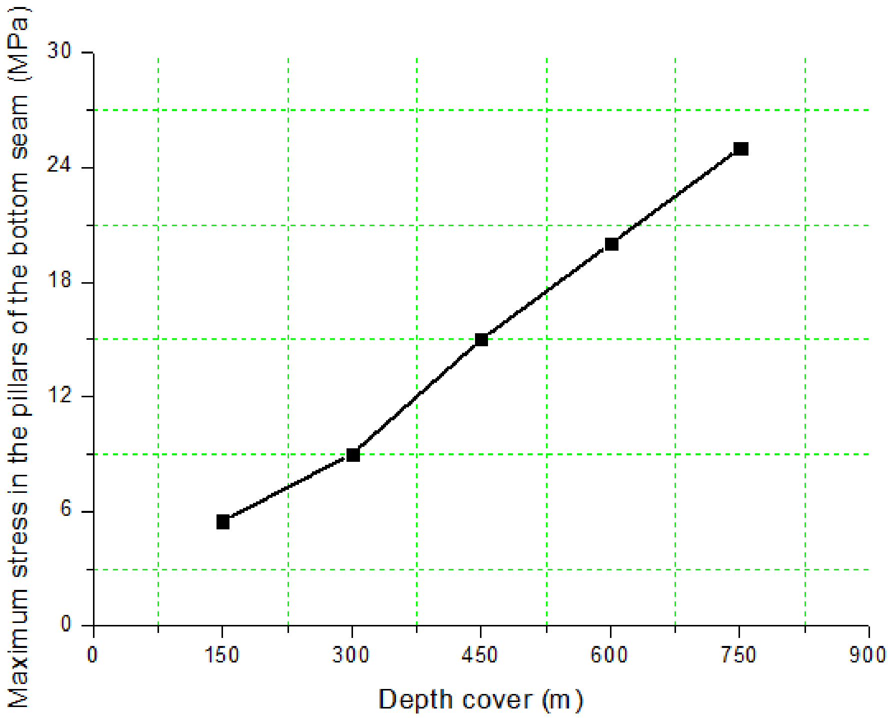


Figure 23 Depth verses stress on pillar of the bottom seam for parting thickness 7 m

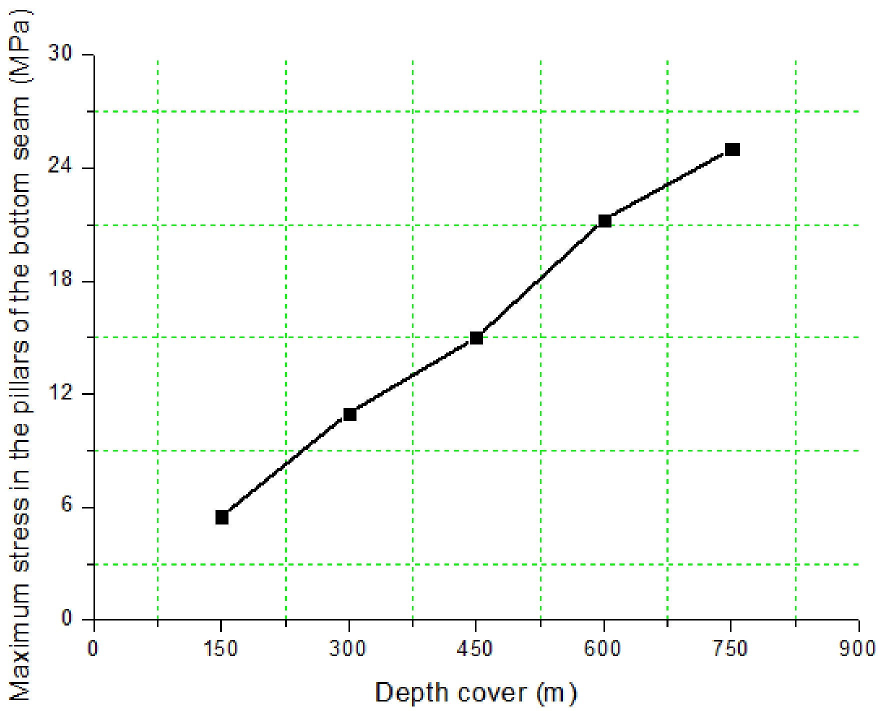


Figure 24 Depth verses stress on pillar of the bottom seam for parting thickness 9 m

Table 9 depth verses maximum stress in stooks at different parting thickness in top seam

Depth	Max Stress in stook at 3 m parting	Max Stress in stook at 5 m parting	Max Stress in stook at 7 m parting	Max Stress in stook at 9 m parting
150	13.75	13.75	13.75	13.75
300	30	30	27.5	25
450	40	40	40	40
600	50	50	50	50
750	50	50	50	50

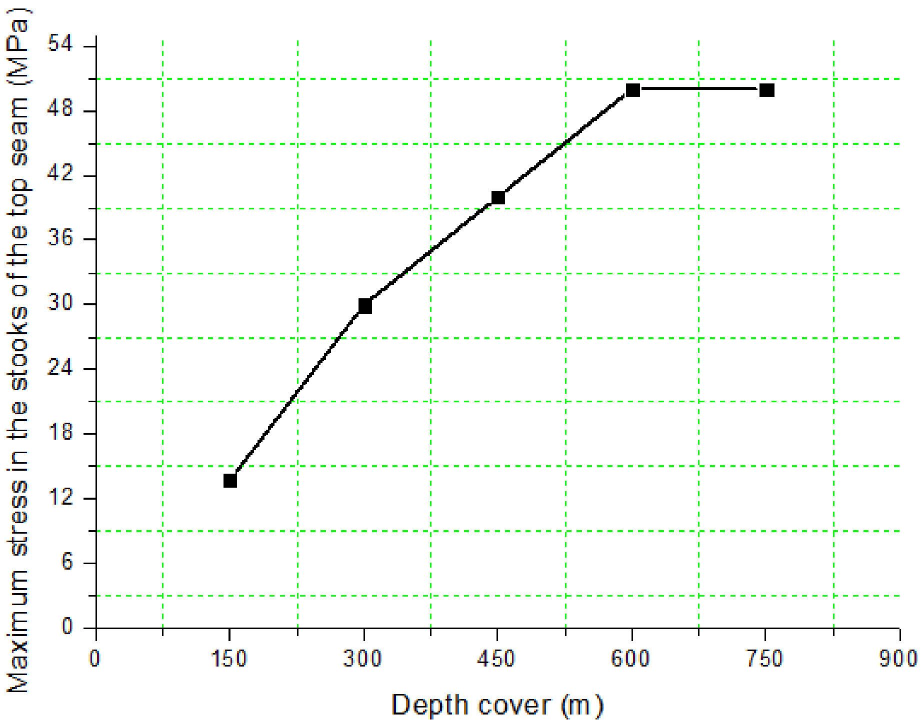


Figure 25 Depth verses stress on stooks of the top seam for parting thickness 3 m

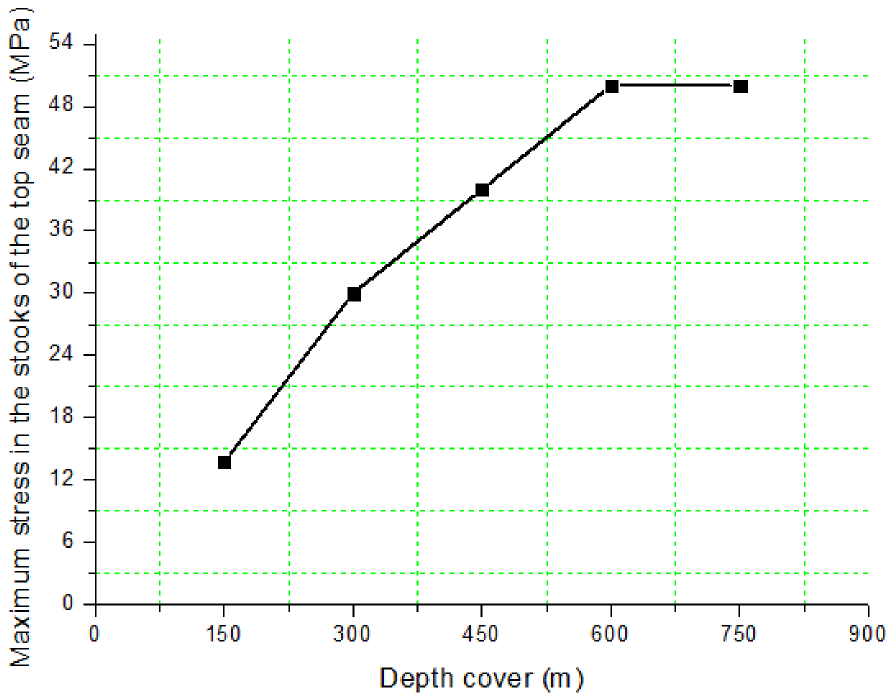


Figure 26 Depth verses stress on stooks of the top seam for parting thickness 3 m

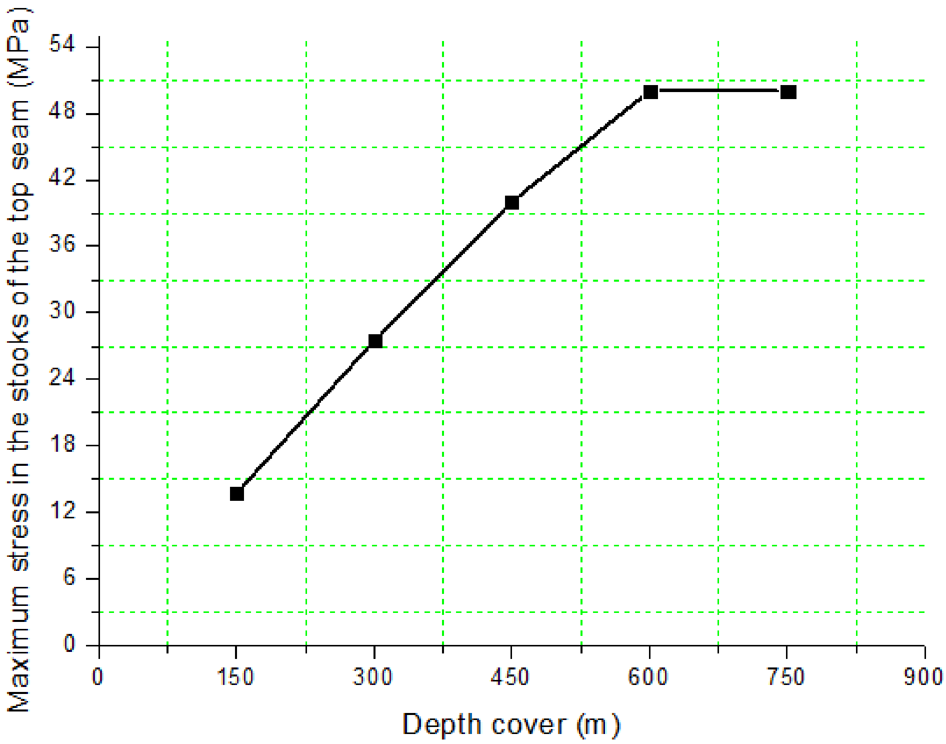


Figure 27 Depth verses stress on stooks of the top seam for parting thickness 3 m

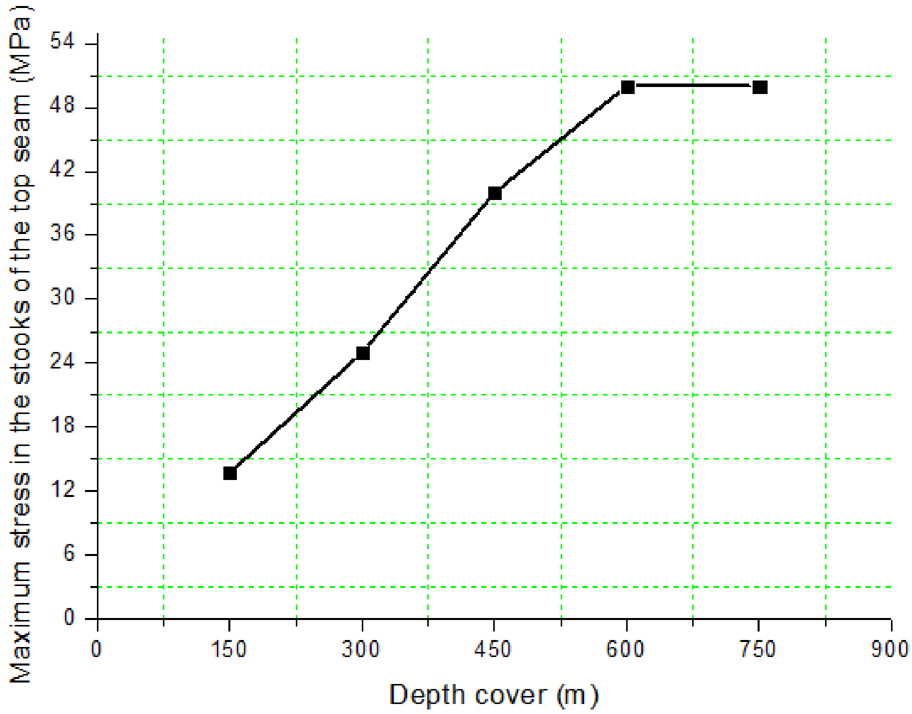


Figure 28 Depth verses stress on stooks of the top seam for parting thickness 3 m

Table 10 Depth verses maximum stress in stook at different parting thickness in bottom seam

Depth	Max Stress in stook at 3 m parting	Max Stress in stook at 5 m parting	Max Stress in stook at 7 m parting	Max Stress in stook at 9 m parting
150	13.75	13.75	13.75	13.75
300	27.5	27.5	27.5	25
450	40	40	40	40
600	50	50	50	50
750	50	70	70	70

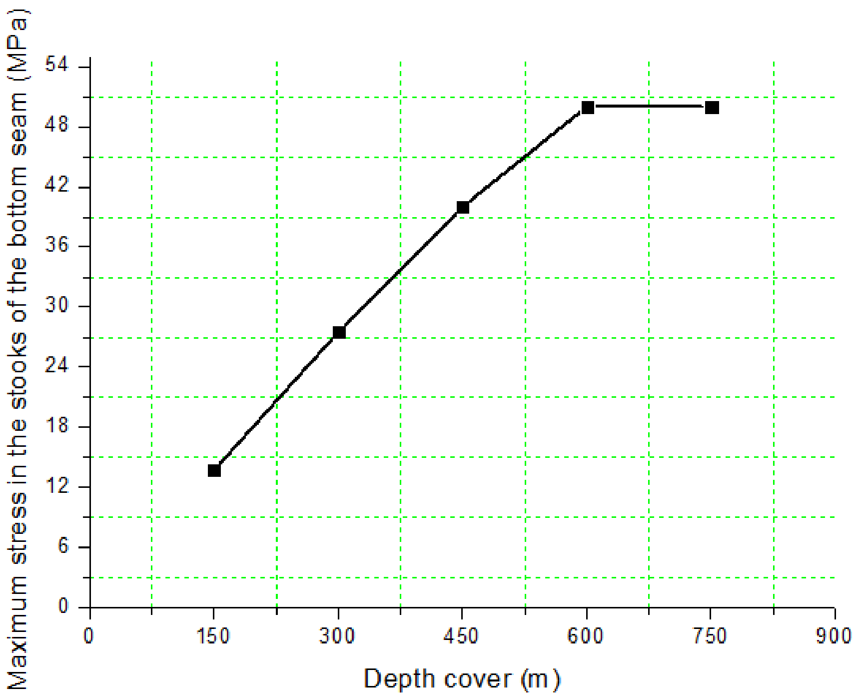


Figure 29 Depth verses stress on stooks of the bottom seam for parting thickness 3 m

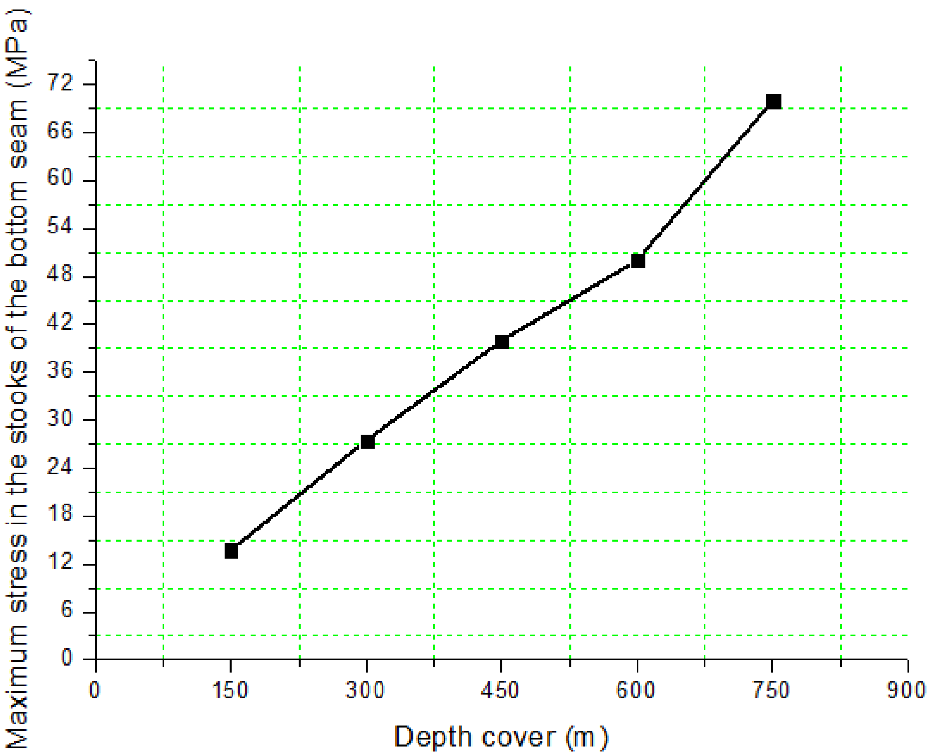


Figure 30 Depth verses stress on stooks of the bottom seam for parting thickness 5 m

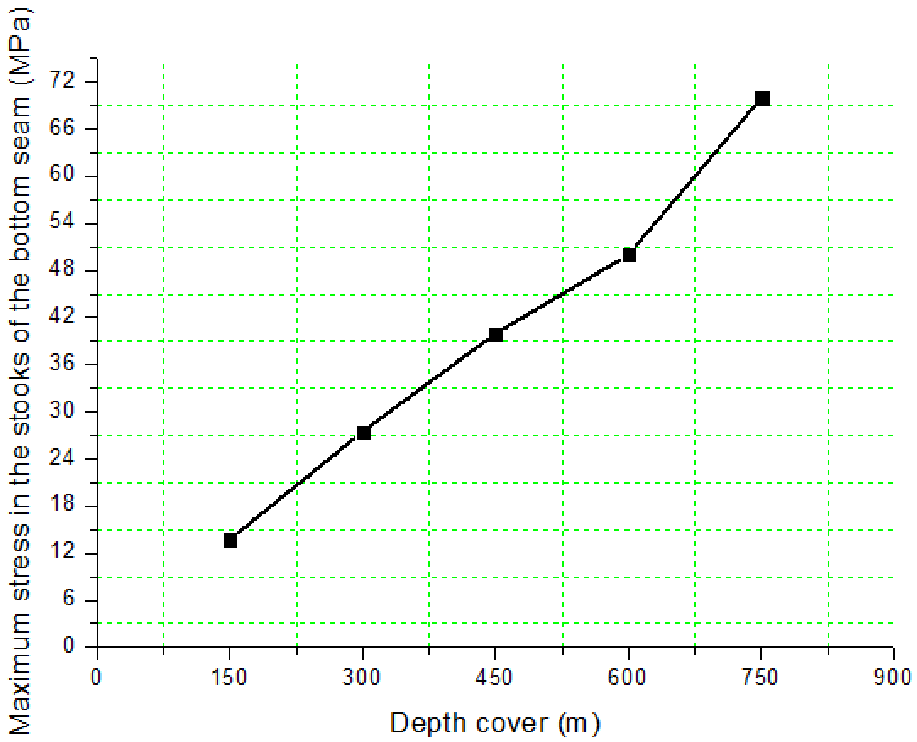


Figure 31 Depth verses stress on stooks of the bottom seam for parting thickness 7 m

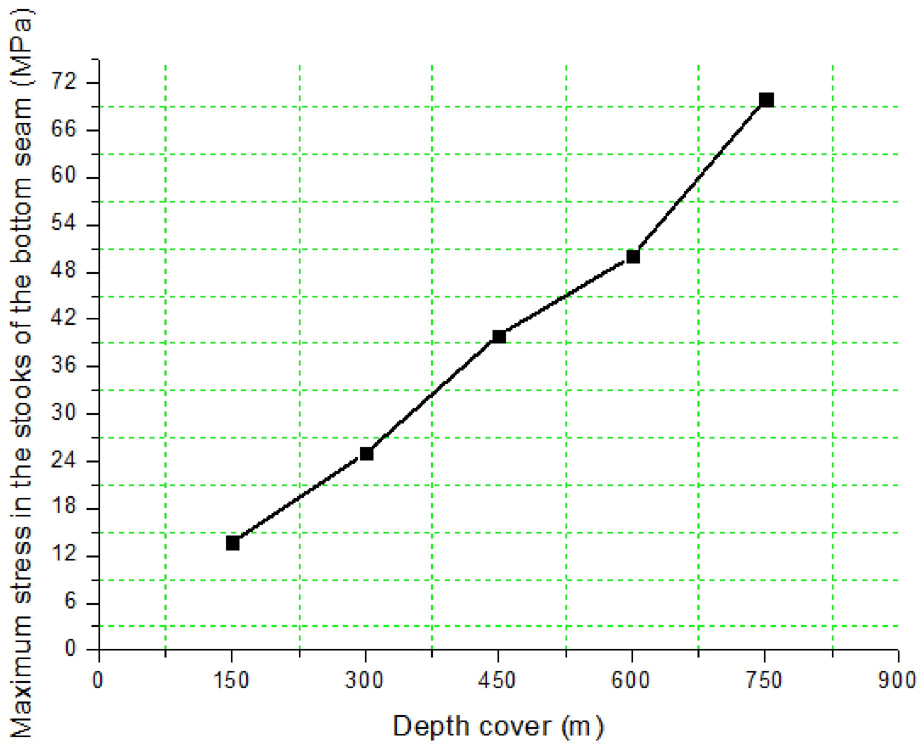


Figure 32 Depth verses stress on stooks of the bottom seam for parting thickness 9 m

Table 11 depth verses maximum stress in rib at different parting thickness for top seam

Depth	Max Stress in rib at 3 m parting	Max Stress in rib at 5 m parting	Max Stress in rib at 7 m parting	Max Stress in rib at 9 m parting
150	13.75	13.75	13.75	13.75
300	17.5	17.5	17.5	22.5
450	17.5	17.5	22.5	27.5
600	15	15	25	25
750	15	15	15	35

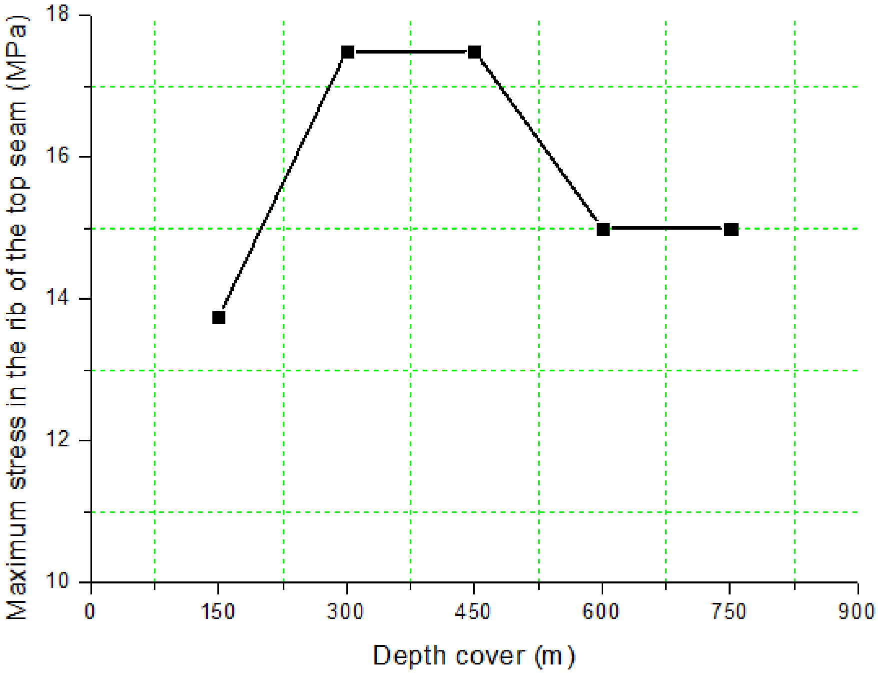


Figure 2 Depth verses stress on rib of the top seam for parting thickness 3 m

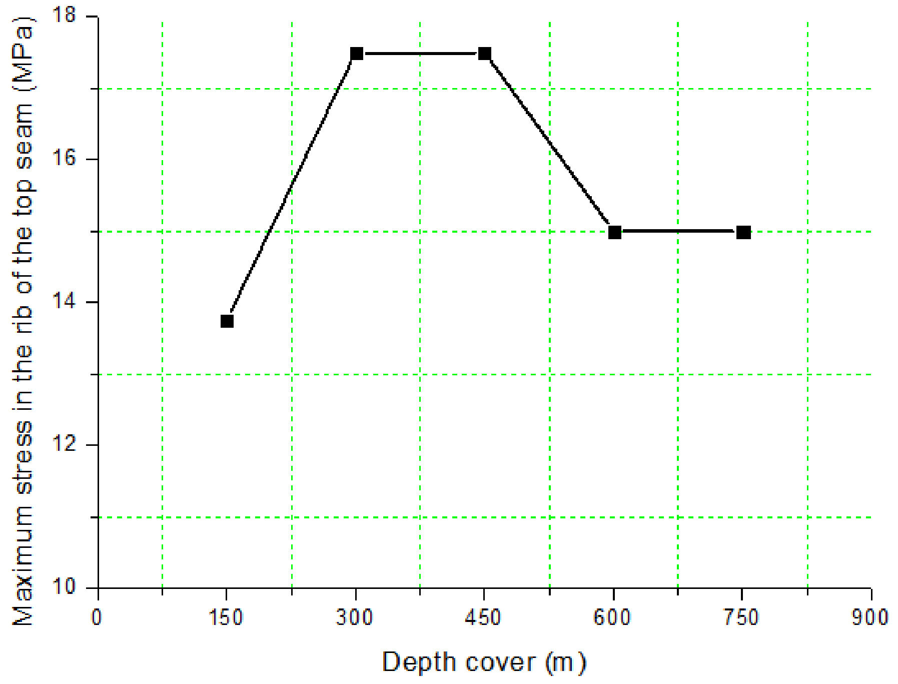


Figure 3 Depth verses stress on rib of the top seam for parting thickness 5 m

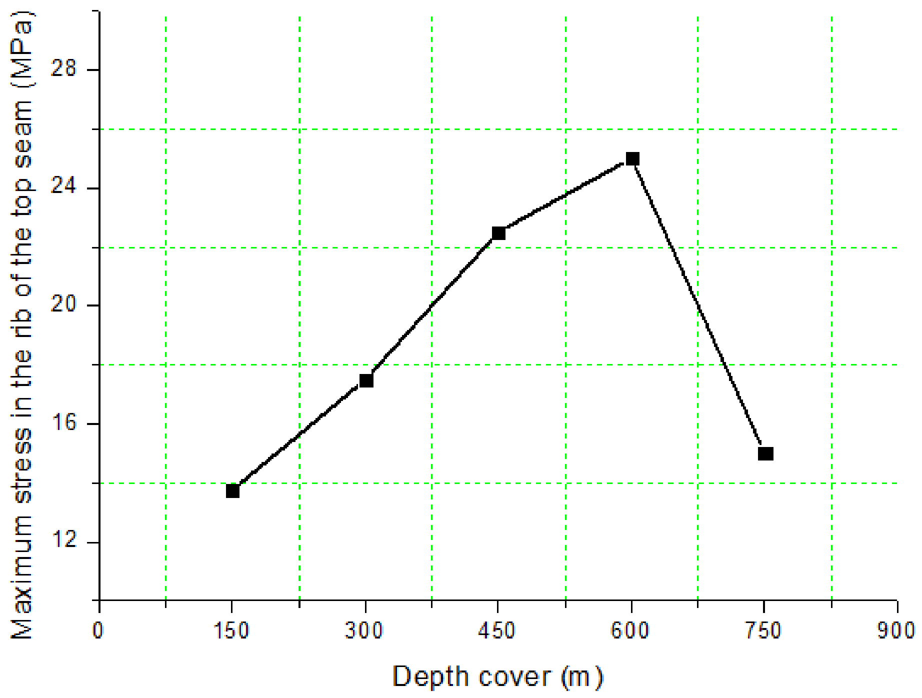


Figure 4 Depth verses stress on rib of the top seam for parting thickness 7 m

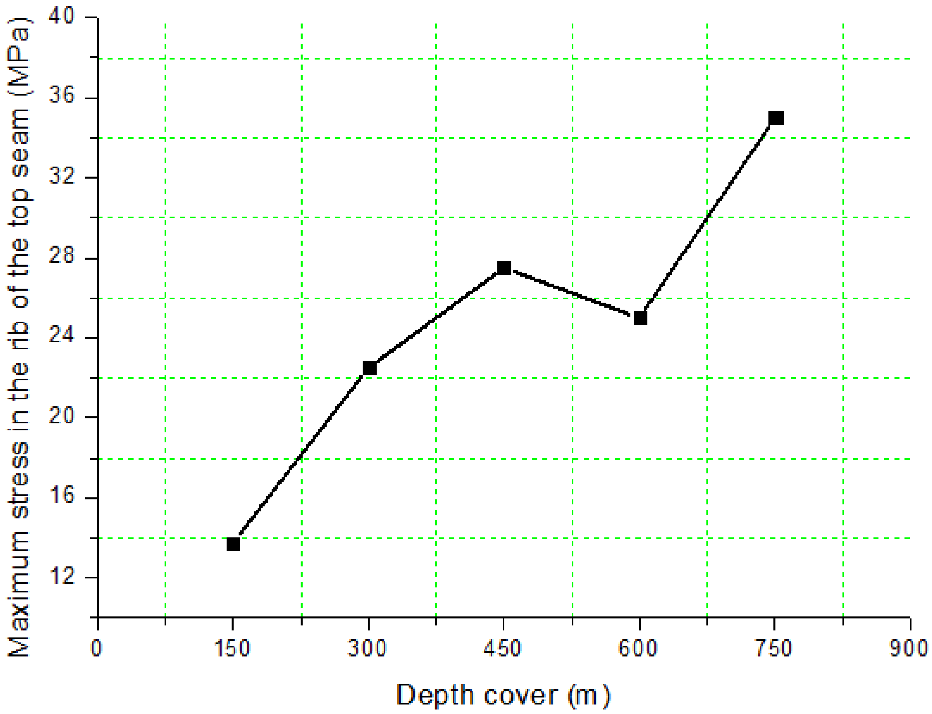


Figure 5 Depth verses stress on rib of the top seam for parting thickness 9 m

Table 12 depth verses maximum stress in rib at different parting thickness for bottom seam

Depth	Max Stress in rib at 3 m parting	Max Stress in rib at 5 m parting	Max Stress in rib at 7 m parting	Max Stress in rib at 9 m parting
150	15	15	15	15
300	17.5	17.5	17.5	17.5
450	17.5	17.5	17.5	17.5
600	15	15	15	15
750	15	15	15	15

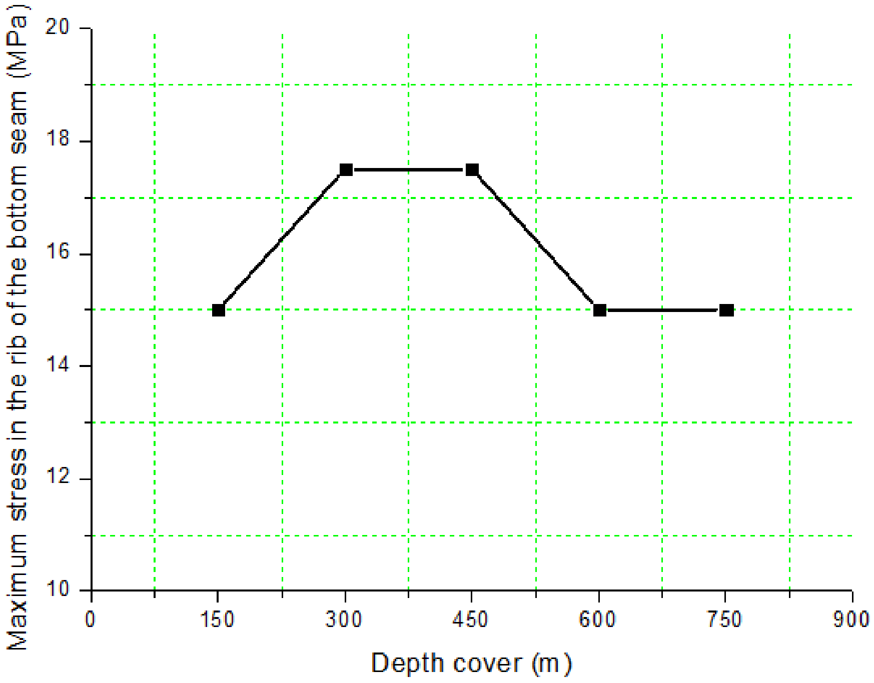


Figure 6 Depth verses stress on rib of the bottom seam for parting thickness 3 m

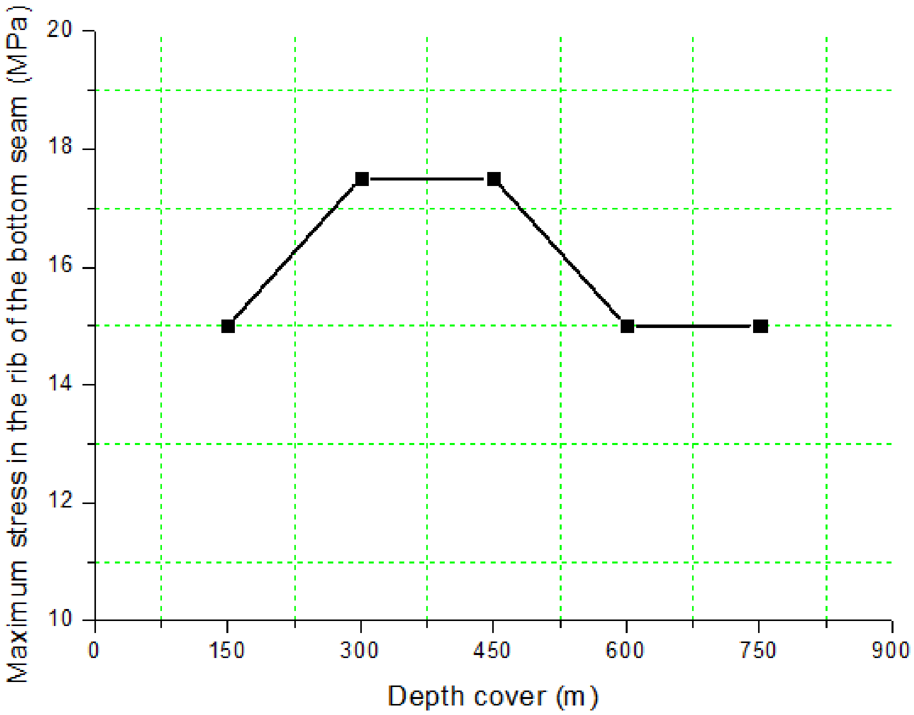


Figure 7 Depth verses stress on rib of the bottom seam for parting thickness 5 m

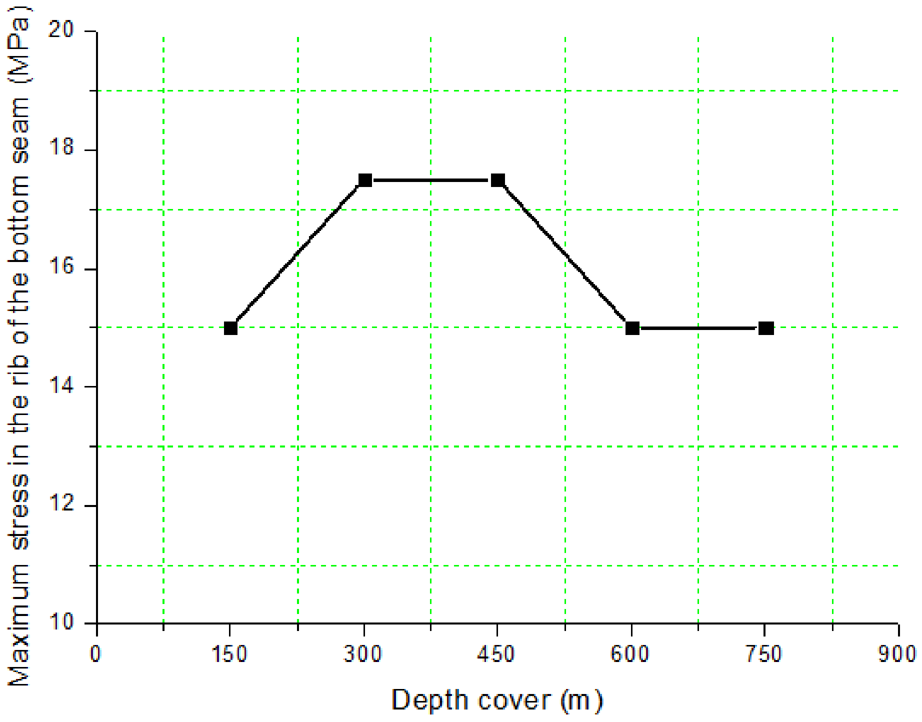


Figure 8 Depth verses stress on rib of the bottom seam for parting thickness 7 m

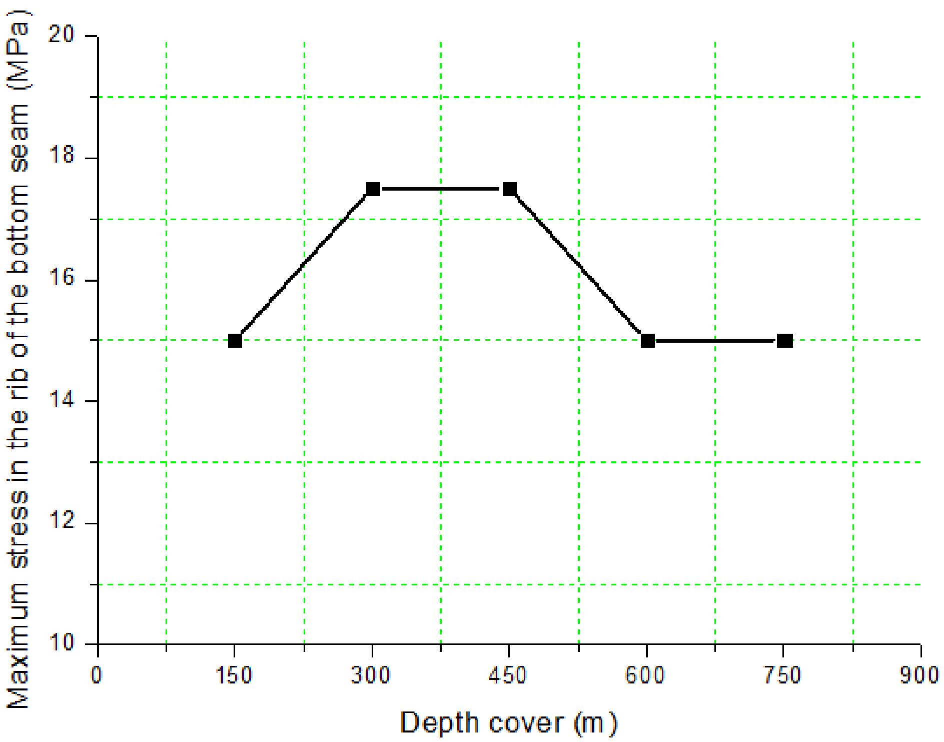


Figure 9 Depth verses stress on rib of the bottom seam for parting thickness 9 m

Table 13 depth verses maximum stress in parting for different parting thickness at development stage

Depth	Max Stress in parting at development stage for 3 m parting	Max Stress in parting at development stage for 5 m parting	Max Stress in parting at development stage for 7 m parting	Max Stress in parting at development stage for 9 m parting
150	2.5	2.5	2.5	2.5
300	5	5	5	5
450	6.25	6.25	6.25	6.25
600	8.75	8.75	8.75	11.25
750	12.5	12.5	12.5	12.5

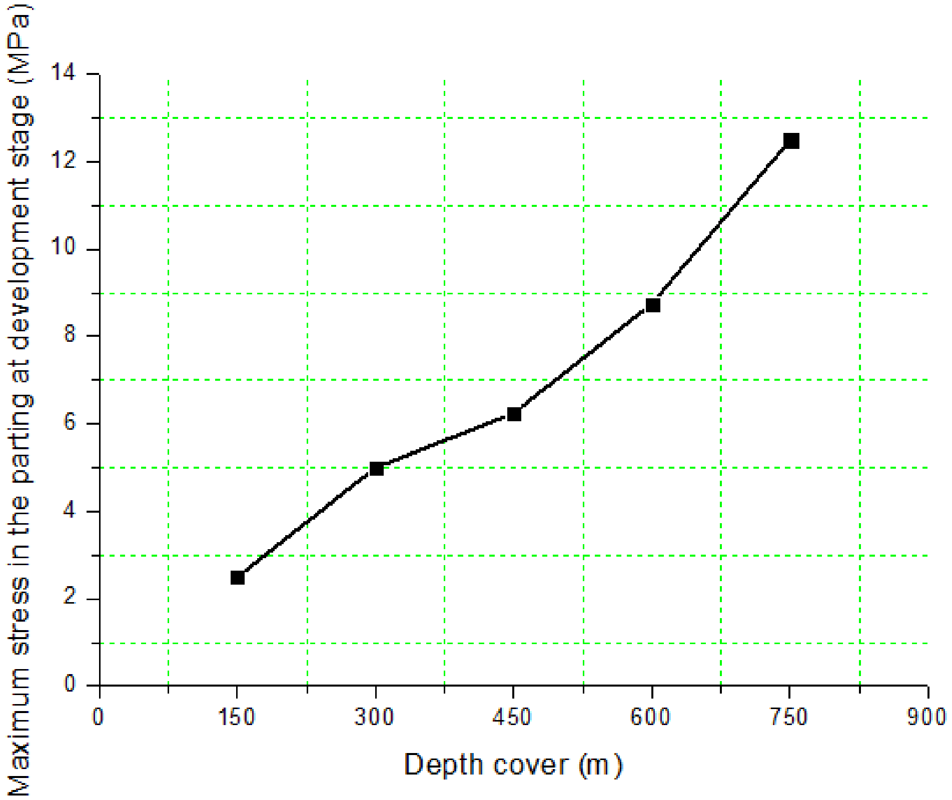


Figure 10 Depth verses stress on parting in development stage for parting thickness 3 m

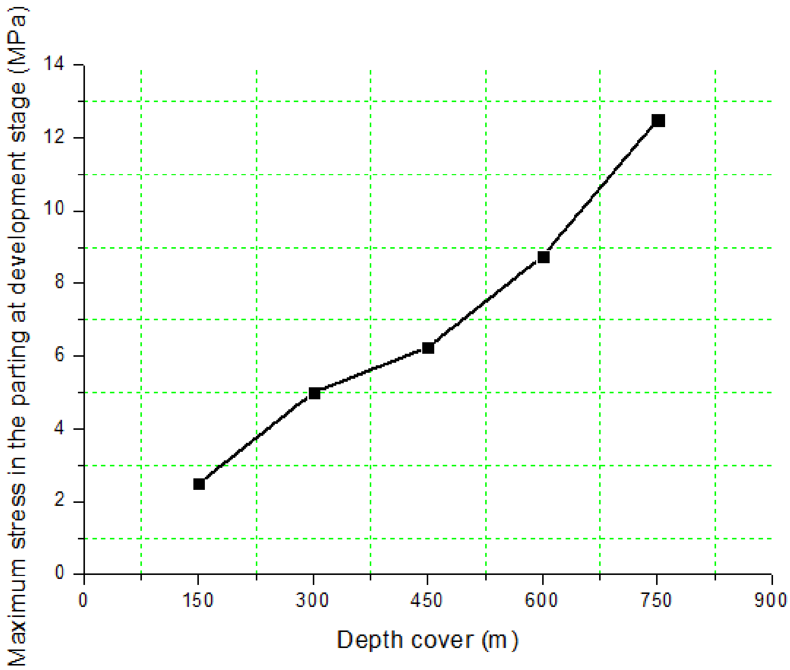


Figure 11 Depth verses stress on parting in development stage for parting thickness 5 m

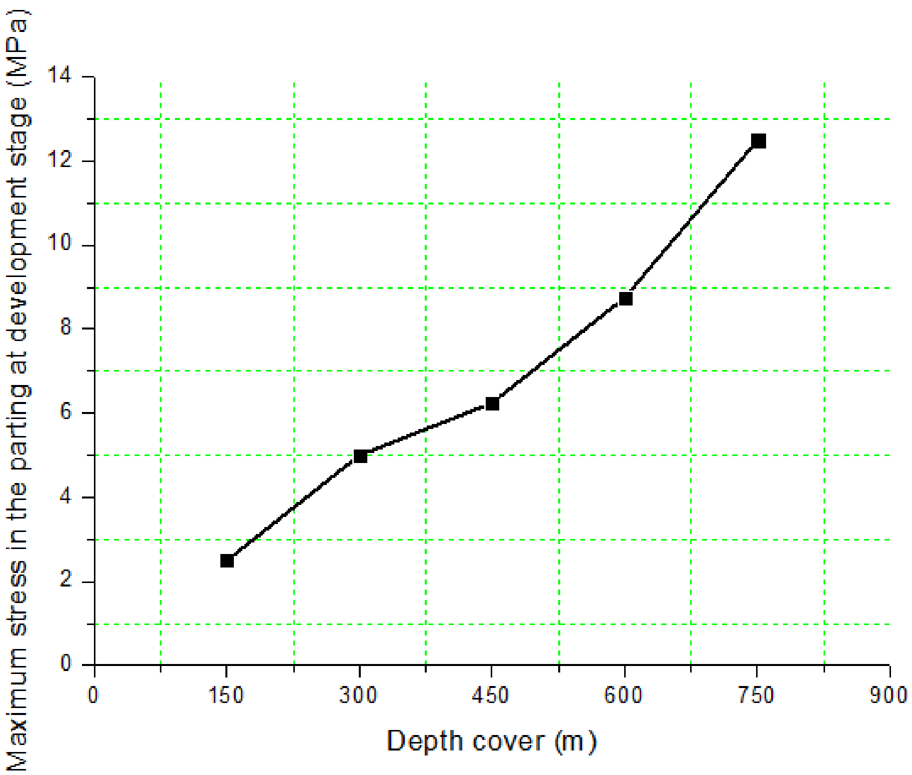


Figure 12 Depth verses stress on parting in development stage for parting thickness 7 m

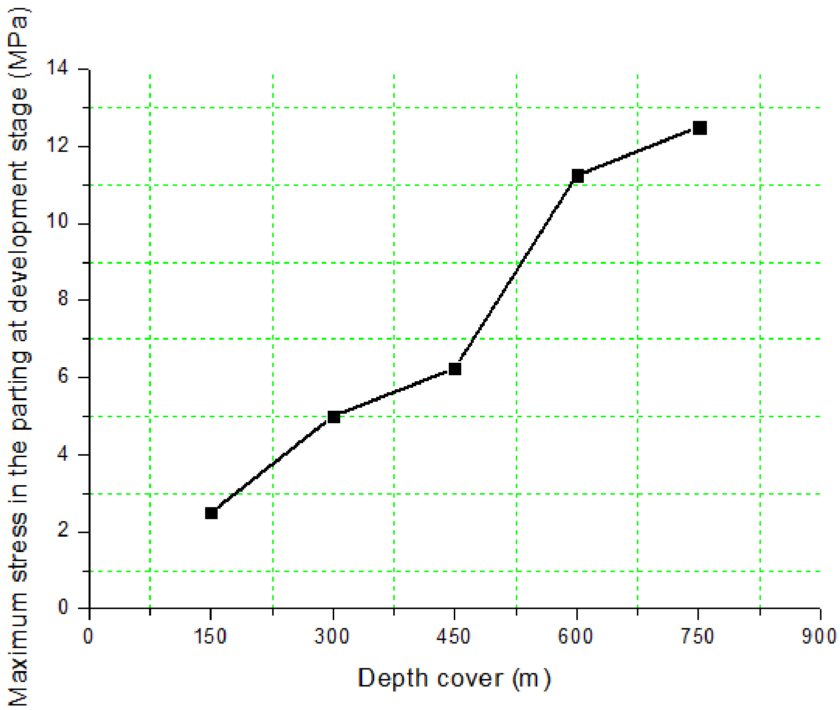


Figure 13 Depth verses stress on parting in development stage for parting thickness 9 m

Table 14 depth verses maximum stress in parting for different parting thickness after excavation of two and a half pillars

Depth	Max Stress in parting after excavation for 3 m parting	Max Stress in parting after excavation for 5 m parting	Max Stress in parting after excavation for 7 m parting	Max Stress in parting after excavation for 9 m parting
150	6.25	6.25	6.25	6.25
300	7.5	12.5	12.5	12.5
450	12.5	17.5	17.5	17.5
600	15	25	15	25
750	25	25	25	25

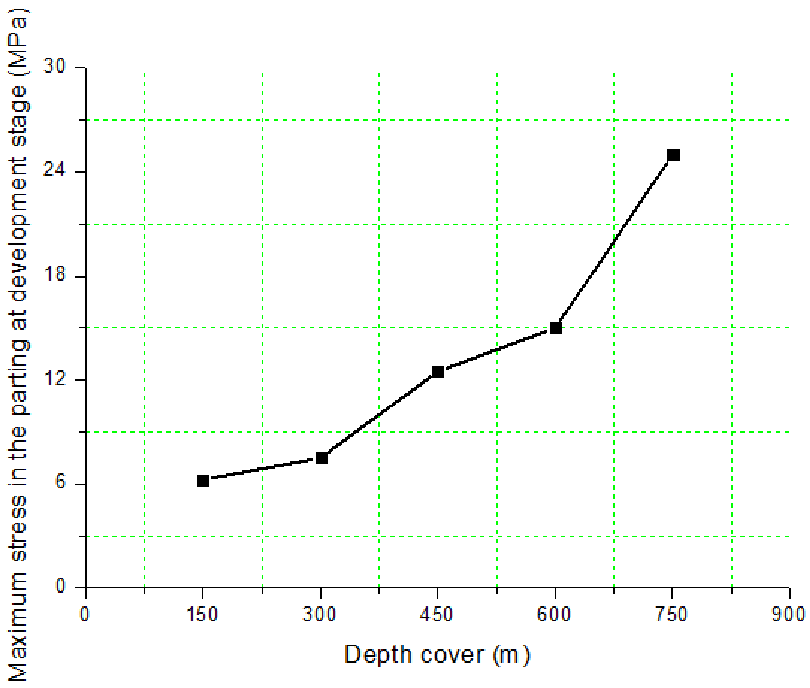


Figure 14 Depth verses stress on parting after excavation of two and a half pillars for parting thickness 3 m

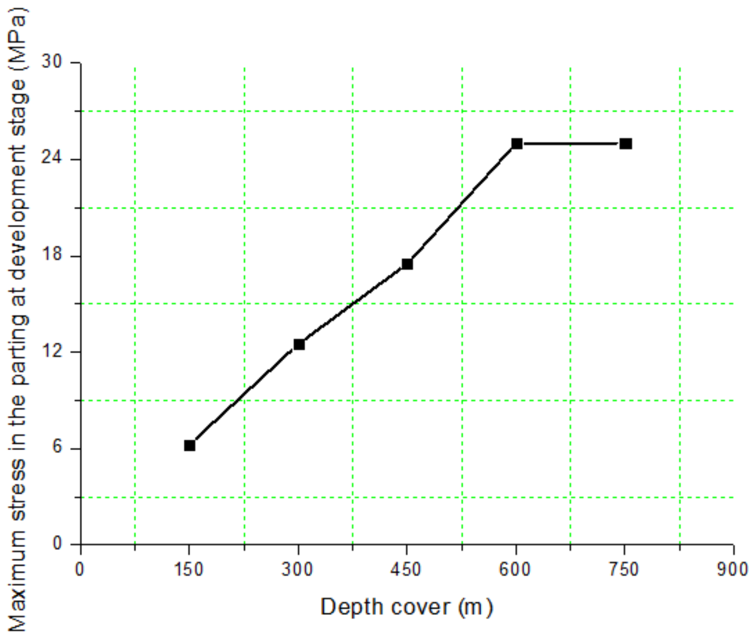


Figure 15 Depth verses stress on parting after excavation of two and a half pillars for parting thickness 5 m

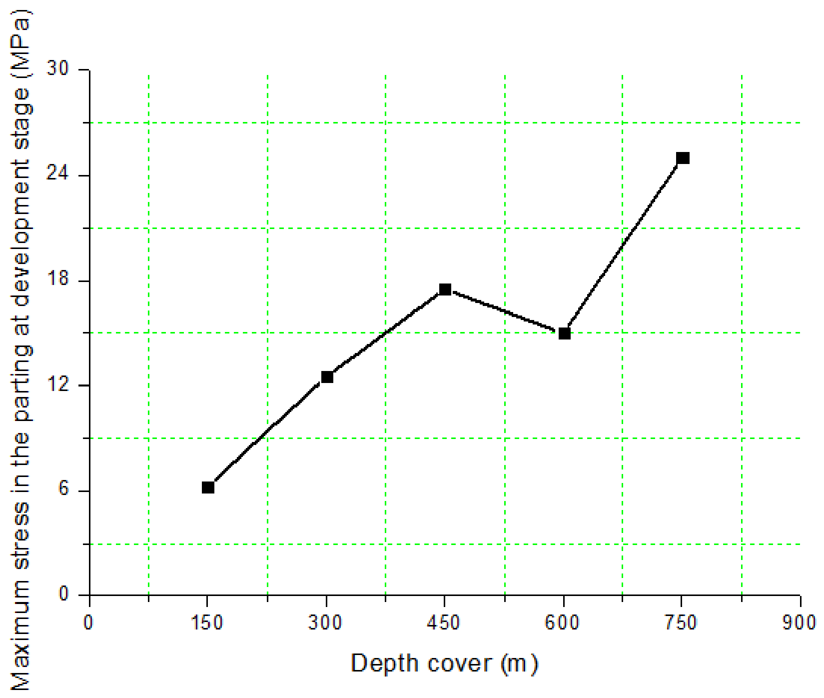


Figure 16 Depth verses stress on parting after excavation of two and a half pillars for parting thickness 7 m

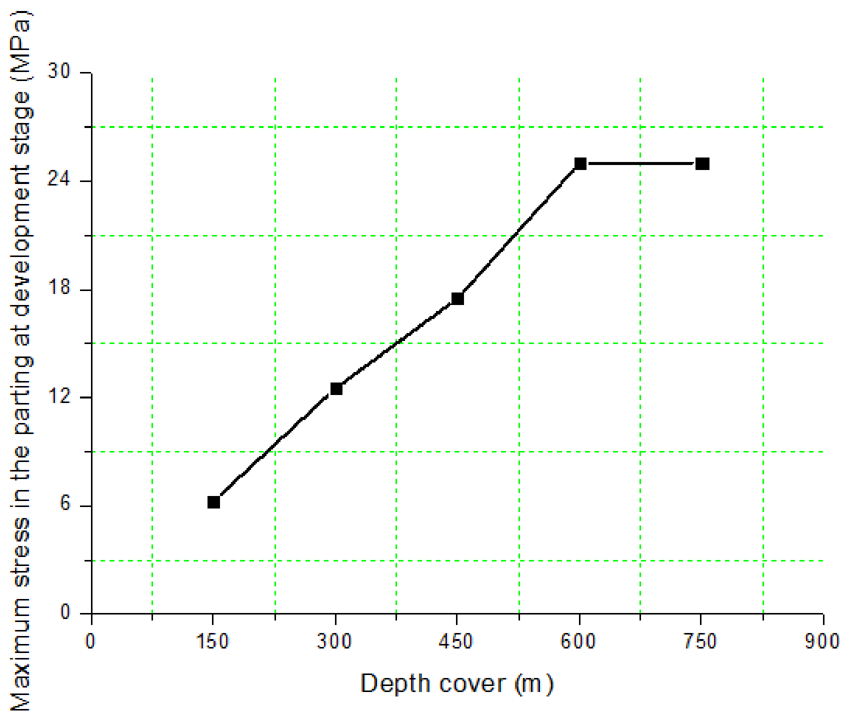


Figure 17 Depth verses stress on parting after excavation of two and a half pillars for parting thickness 9 m

** all stresses were measured in MPa.

4.3 ANALYSIS:

4.3.1 Analysis of effect of parting thickness on stress behaviour over pillars, stooks and ribs and parting between the seams:

The effects can be divided in three main parts, viz effect on top seam, effect on bottom seam and effect on parting:

4.3.1.1 Effect on top seam:

Effect on pillars: The change in parting thickness has very little effect on the maximum stress in the top seam. It seems that the change in parting thickness has no effect on the stress in pillars for shallow depth covers. But as depth cover increases the parting thickness shows very slight effect. The maximum stress increases with increase in parting thickness. The minimum stress was 5.5 MPa for 150 m depth cover and 3 m parting and maximum stress was 25 MPa for 750 m depth cover and 9 m parting.

Effect on stooks: With increase in parting thickness the maximum stress on stooks remained constant. It seems the parting thickness has no effect on stress distribution in stooks. The minimum stress was 13.75 MPa for 150 m depth cover and 3 m parting and maximum stress was 50 MPa for 750 m depth cover and 9 m parting.

Effect on rib: The maximum stress in the rib increases with increasing parting thickness. The effect is lower for shallow depth, while it was much pronounced for deep covers. The minimum stress was 13.75 MPa for 150 m depth cover and 3 m parting and maximum stress was 35 MPa for 750 m depth cover and 9 m parting.

4.3.1.2 Effect on bottom seam:

Effect on pillars: The change in parting thickness has a more pronounced effect for the bottom seam. But it still follows the same trend as the top seam. The maximum stress increases with increase in parting thickness. Only that the effect is more pronounced. It has no effect for shallow depth covers. But as the depth cover increases the effect becomes very pronounced. The minimum stress was 5.5 MPa for 150 m depth cover and 3 m parting and maximum stress was 28 MPa for 750 m depth cover and 5 m parting.

Effect on stooks: With increase in parting thickness the maximum stress on stooks remained constant. It seems the parting thickness has no effect on stress distribution stooks. The minimum stress was 19.75 MPa for 150 m depth cover and 3 m parting and maximum stress was 50 MPa for 750 m depth cover and 9 m parting.

Effect on rib: With increase in parting thickness the maximum stress on rib remained constant. It seems the parting thickness has no effect on stress distribution rib. The minimum stress was 13.75 MPa for 150 m depth cover and 3 m parting and maximum stress was 17.5 MPa for 450 m depth cover and 5 m parting.

4.3.1.3 Effect on parting:

Effect on parting after development stage: With increase in parting thickness the maximum stress in the parting remained more or less constant. It seems the parting thickness has very little effect on stress distribution in the parting. The minimum stress was 2.5 MPa for 150 m depth cover and 3 m parting and maximum stress was 12.5 MPa for 750 m depth cover and 9 m parting.

Effect on parting after excavation of two and a half pillars with a rib: With increase in parting thickness the maximum stress in the parting remained constant. It seems the change in parting thickness has very little effect on stress distribution in the parting. The minimum stress was 6.25 MPa for 150 m depth cover and 3 m parting and maximum stress was 25 MPa for 750 m depth cover and 9 m parting.

4.3.2 Analysis of effect of depth covers on stress behaviour over pillars, stooks and ribs and parting between the seams:

Again the effect can be studied better by dividing them in three categories, namely, effect on top seam, bottom seam and parting.

4.3.2.1 Effect on top seam:

Effect on pillars: The maximum stress in the pillars in the top seam increases with increase in depth cover. The effect is more pronounced for higher parting thickness while for lower seam thickness it is considerably less. For example for 9 m parting, the minimum stress was 5.5 MPa for 150 m depth cover and maximum stress was 25 MPa for 750 m depth cover.

Effects on stooks: With increase in depth cover the maximum stress on stooks increased. But there was no change in this increase with increase in parting thickness. It remained almost equal to the other parting. For example for 9 m parting, the minimum stress was 13.75 MPa for 150 m depth cover and maximum stress was 50 MPa for 750 m depth cover.

Effect on rib: The maximum stress on the rib increases with increase in depth at first. This trend continues from shallow depth to moderated depth. Then it was found that the stress in the ribs decreased with further increase in depth covers. It may be concluded that the ribs yielded and failed for greater depth covers. The change in parting thickness showed increase in maximum stress in rib. But the above said trend still continued. For example for 3 m parting, the minimum stress was 13.75 MPa for 150 m depth cover and maximum stress was 15 MPa for 750 m depth cover.

4.3.2.2 Effect on bottom seam:

Effect on pillars: The increase in depth cover tends to increase the maximum stress in the bottom seam. The effect was nearly equal for all parting thicknesses. For 3 m parting thickness the effect was even slighter than others. For example for 9 m parting, the minimum stress was 5.5 MPa for 150 m depth cover and maximum stress was 25 MPa for 750 m depth cover.

Effects on stooks: With increase in depth cover the maximum stress on stooks increased. But there was no change in this increase with increase in parting thickness. It remained almost equal to the other parting. For example for 9 m parting, the minimum stress was 13.75 MPa for 150 m depth cover and maximum stress was 70 MPa for 750 m depth cover.

Effect on rib: The maximum stress on the rib increases with increase in depth at first. This trend continues from shallow depth to moderated depth. Then it was found that the stress in the ribs decreased with further increase in depth covers. It may be concluded that the ribs yielded and failed for greater depth covers. The change in parting thickness showed no effect on maximum stress in rib. For example for 3 m parting, the minimum stress was 15 MPa for 150 m depth cover and maximum stress was 15 MPa for 750 m depth cover.

4.3.2.3 Effect on parting between the seams:

Effect on parting after development stage: The stress in the parting thickness increased with increase in depth cover. It was lower for shallow depth, more for moderate depth and increased further for higher depth. The change in parting thickness had little effect on maximum stress in the parting. It remained more or less same, except for the 3 m parting. For 3 m parting the maximum stress was still lower.

Effect on parting after excavation of two and a half pillars with a rib: The stress in the parting thickness increased with increase in depth cover. It was lower for shallow depth, more for moderate depth and increased further for higher depth. The change in parting thickness increased maximum stress in the parting.

CHAPTER 5

CONCLUSIONS AND SUGGESTIONS

CONCLUSIONS and SUGGESTIONS

5.1 CONCLUSION

Maximum stress induced in the pillars and parting after development and, stooks, ribs and parting after extraction of two and a half pillars were estimated. For this purpose five different depth covers were considered (150 m, 300 m, 450 m, 600 m and 750 m). In these two was for shallow depth, one for moderate depth and two for higher depth. Four different parting thicknesses for each depth were considered (3 m, 5 m, 7 m and 9 m). Overall 20 different models were simulated for this purpose. Finite difference code method was used for the study. The software used was two dimensional FLAC. Depending on the results obtained from the numerical models, following conclusions were drawn:

1) The maximum stress increased in pillars after development stage in both the seams, with increase in parting thickness. The effect observed was little for top seam while more for bottom seam.
2) Change in parting thickness had no effect in stooks for both the seams.
3) The maximum stress increased in the ribs for the top seam with increase in parting thickness but remained more or less constant for the bottom seam. The maximum stress in the parting remained constant for both after excavation of two and a half pillars for change in parting thickness.
4) The maximum stress increased in pillars and stooks for both top and the bottom seams for increasing depth covers.
5) The maximum stress increased in ribs first and then decreased, for increasing depth covers. The ribs seem to have yielded after moderate depth.
6) The maximum stress in parting after development stage increased with increase in the depth cover.
7) The maximum stress in parting after extraction of two and a half pillars increased with increase in depth covers.

5.2 SUGGESTIONS

Use of numerical modelling in mining industries has been constantly on a rise. It helps in pre-assessment of the conditions to be met in the real life and hence adequate precautions can be taken. The numerical modelling is continuously on development and still has a large scope in the future. Various adverse incidents of rock bursts have occurred in mines. Even these can now be studied in a 3 dimensional numerical modelling. Different models can be used to study the support designs at different places of mines in both 2 dimensions and3 dimensions.

We can further study the above project by simulating similar conditions in a 3 dimension model. The results can be compared and recorded. It will help in gaining the real picture of the scenario. The results between 2D and 3D models can be compared. The one which suits the field data and observation shall be taken. The comparison would also serve as a critique between 2D and 3D models. The simulated data can also be compared with field statistics and finding. This will help in gaining a better understanding of the picture.

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ANNEXURE

SAMPLE NUMERICAL MODEL PROGRAM FOR 3 M THICK SEAM AT 150 M DEPTH:

The conditions used in the program are given below:

- Grid sizes 79 in x direction and 33 in y direction
- No of coal seams 2
- Height of top seam 3 m
- Height of bottom seam 3 m
- Parting between the seams 3 m – 9 m at a step of 2 m
- Depth cover 150 m – 750 m at a step of 150 m

The following program can be used a sample program that was generated in the simulation.

```
New
Title
Anubhav Gaurav(final year project)
* Gallery size=4.8m X 3m, Width of split=5m; Rib thickness=2.5m
*PARAMETRIC STUDIES
* Seam thickness=3-11m @2m, Pillar size=25m, Depth=30-240m @30m
* Gallery size=4.8m X 3m, Width of split=5m; Rib thickness=2.5m
GR 78 32
M M
gen 0,0 0,100 60,100 60,0                        R .8 .8     I 1 8   J 1 12
gen 60,0 60,100 64.8,100 64.8,0                  R 1 .8      I 8 12  J 1 12
gen 64.8,0 64.8,100 72.25,100 72.25,0            R 1 .8      I 12 17 J 1 12
gen 72.25,0 72.25,100 77.25,100 77.25,0          R 1 .8      I 17 19 J 1 12
gen 77.25,0 77.25,100 85,100 85,0                R 1 .8      I 19 24 J 1 12
gen 85,0 85,100 89.8,100 89.8,0                  R 1 .8      I 24 28 J 1 12
gen 89.8,0 89.8,100 92.3,100 92.3,0              R 1 .8      I 28 33 J 1 12
gen 92.3,0 92.3,100 97.25,100 97.25,0            R 1 .8      I 33 38 J 1 12
gen 97.25,0 97.25,100 102.25,100 102.25,0        R 1 .8      I 38 43 J 1 12
gen 102.25,0 102.25,100 110,100 110,0            R 1 .8      I 43 45 J 1 12
gen 110,0 110,100 114.8,100 114.8,0              R 1 .8      I 45 49 J 1 12
gen 114.8,0 114.8,100 117.3,100 117.3,0          R 1 .8      I 49 54 J 1 12
gen 117.3,0 117.3,100 122.25,100 122.25,0        R 1 .8      I 54 59 J 1 12
gen 122.25,0 122.25,100 127.25,100 127.25,0      R 1 .8      I 59 61 J 1 12
gen 127.25,0 127.25,100 135,100 135,0            R 1 .8      I 61 66 J 1 12
gen 135,0 135,100 139.8,100 139.8,0              R 1 .8      I 66 70 J 1 12
gen 139.8,0 139.8,100 200,100 200,0              R 1.2 .8    I 70 79 J 1 12
*Coal seam -3m
gen 0,100 0,103 60,103 60,100                    R .8 1      I 1 8   J 12 15
gen 60,100 60,103 64.8,103 64.8,100              R 1 1       I 8 12  J 12 15
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gen 64.8,100 64.8,103 72.25,103 72.25,100          R 1 1      I 12 17  J 12 15
gen 72.25,100 72.25,103 77.25,103 77.25,100        R 1 1      I 17 19  J 12 15
gen 77.25,100 77.25,103 85,103 85,100              R 1 1      I 19 24  J 12 15
gen 85,100 85,103 89.8,103 89.8,100                R 1 1      I 24 28  J 12 15
gen 89.8,100 89.8,103 92.3,103 92.3,100            R 1 1      I 28 33  J 12 15
gen 92.3,100 92.3,103 97.25,103 97.25,100          R 1 1      I 33 38  J 12 15
gen 97.25,100 97.25,103 102.25,103 102.25,100      R 1 1      I 38 43  J 12 15
gen 102.25,100 102.25,103 110,103 110,100          R 1 1      I 43 45  J 12 15
gen 110,100 110,103 114.8,103 114.8,100            R 1 1      I 45 49  J 12 15
gen 114.8,100 114.8,103 117.3,103 117.3,100        R 1 1      I 49 54  J 12 15
gen 117.3,100 117.3,103 122.25,103 122.25,100      R 1 1      I 54 59  J 12 15
gen 122.25,100 122.25,103 127.25,103 127.25,100    R 1 1      I 59 61  J 12 15
gen 127.25,100 127.25,103 135,103 135,100          R 1 1      I 61 66  J 12 15
gen 135,100 135,103 139.8,103 139.8,100            R 1 1      I 66 70  J 12 15
gen 139.8,100 139.8,103 200,103 200,100            R 1.2 1    I 70 79 J 12 15
*sandstone
gen 0,103 0,106 60,106 60,103                      R .8 1     I 1 8    J 15 20
gen 60,103 60,106 64.8,106 64.8,103                R 1 1      I 8 12   J 15 20
gen 64.8,103 64.8,106 72.25,106 72.25,103          R 1 1      I 12 17  J 15 20
gen 72.25,103 72.25,106 77.25,106 77.25,103        R 1 1      I 17 19  J 15 20
gen 77.25,103 77.25,106 85,106 85,103              R 1 1      I 19 24  J 15 20
gen 85,103 85,106 89.8,106 89.8,103                R 1 1      I 24 28  J 15 20
gen 89.8,103 89.8,106 92.3,106 92.3,103            R 1 1      I 28 33  J 15 20
gen 92.3,103 92.3,106 97.25,106 97.25,103          R 1 1      I 33 38  J 15 20
gen 97.25,103 97.25,106 102.25,106 102.25,103      R 1 1      I 38 43  J 15 20
gen 102.25,103 102.25,106 110,106 110,103          R 1 1      I 43 45  J 15 20
gen 110,103 110,106 114.8,106 114.8,103            R 1 1      I 45 49  J 15 20
gen 114.8,103 114.8,106 117.3,106 117.3,103        R 1 1      I 49 54  J 15 20
gen 117.3,103 117.3,106 122.25,106 122.25,103      R 1 1      I 54 59  J 15 20
gen 122.25,103 122.25,106 127.25,106 127.25,103    R 1 1      I 59 61  J 15 20
gen 127.25,103 127.25,106 135,106 135,103          R 1 1      I 61 66  J 15 20
gen 135,103 135,106 139.8,106 139.8,103            R 1 1      I 66 70  J 15 20
gen 139.8,103 139.8,106 200,106 200,103            R 1.2 1    I 70 79  J 15 20
*Coal seam -3m
gen 0,106 0,109 60,109 60,106                      R .8 1     I 1 8    J 20 23
gen 60,106 60,109 64.8,109 64.8,106                R 1 1      I 8 12   J 20 23
gen 64.8,106 64.8,109 72.25,109 72.25,106          R 1 1      I 12 17  J 20 23
gen 72.25,106 72.25,109 77.25,109 77.25,106        R 1 1      I 17 19  J 20 23
gen 77.25,106 77.25,109 85,109 85,106              R 1 1      I 19 24  J 20 23
gen 85,106 85,109 89.8,109 89.8,106                R 1 1      I 24 28  J 20 23
gen 89.8,106 89.8,109 92.3,109 92.3,106            R 1 1      I 28 33  J 20 23
gen 92.3,106 92.3,109 97.25,109 97.25,106          R 1 1      I 33 38  J 20 23
gen 97.25,106 97.25,109 102.25,109 102.25,106      R 1 1      I 38 43  J 20 23
gen 102.25,106 102.25,109 110,109 110,106          R 1 1      I 43 45  J 20 23
gen 110,106 110,109 114.8,109 114.8,106            R 1 1      I 45 49  J 20 23
gen 114.8,106 114.8,109 117.3,109 117.3,106        R 1 1      I 49 54  J 20 23
gen 117.3,106 117.3,109 122.25,109 122.25,106      R 1 1      I 54 59  J 20 23
gen 122.25,106 122.25,109 127.25,109 127.25,106    R 1 1      I 59 61  J 20 23
gen 127.25,106 127.25,109 135,109 135,106          R 1 1      I 61 66  J 20 23
gen 135,106 135,109 139.8,109 139.8,106            R 1 1      I 66 70  J 20 23
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gen 139.8,106 139.8,109 200,109 200,106                     R 1.2 1           I 70 79 J 20 23
*graphite
gen 0,109 0,259 60,259 60,109                               R .8 1.2          I 1 8    J 23 33
gen 60,109 60,259 64.8,259 64.8,109                         R 1 1.2           I 8 12   J 23 33
gen 64.8,109 64.8,259 72.25,259 72.25,109                   R 1 1.2           I 12 17  J 23 33
gen 72.25,109 72.25,259 77.25,259 77.25,109                 R 1 1.2           I 17 19  J 23 33
gen 77.25,109 77.25,259 85,259 85,109                       R 1 1.2           I 19 24  J 23 33
gen 85,109 85,259 89.8,259 89.8,109                         R 1 1.2           I 24 28  J 23 33
gen 89.8,109 89.8,259 92.3,259 92.3,109                     R 1 1.2           I 28 33  J 23 33
gen 92.3,109 92.3,259 97.25,259 97.25,109                   R 1 1.2           I 33 38  J 23 33
gen 97.25,109 97.25,259 102.25,259 102.25,109               R 1 1.2           I 38 43  J 23 33
gen 102.25,109 102.25,259 110,259 110,109                   R 1 1.2           I 43 45  J 23 33
gen 110,109 110,259 114.8,259 114.8,109                     R 1 1.2           I 45 49  J 23 33
gen 114.8,109 114.8,259 117.3,259 117.3,109                 R 1 1.2           I 49 54  J 23 33
gen 117.3,109 117.3,259 122.25,259 122.25,109               R 1 1.2           I 54 59  J 23 33
gen 122.25,109 122.25,259 127.25,259 127.25,109             R 1 1.2           I 59 61  J 23 33
gen 127.25,109 127.25,259 135,259 135,109                   R 1 1.2           I 61 66  J 23 33
gen 135,109 135,259 139.8,259 139.8,109                     R 1 1.2           I 66 70  J 23 33
gen 139.8,109 139.8,259 200,259 200,109                     R 1.2 1.2         I 70 79  J 23 33
PROP  S=4.E9   B=6.67E9   D=2300 T=9.E6   C= 12.E6     FRIC=45        I 1 78 J 1 11
PROP  S=4.E9     B=6.67E9  D=2300 T=9.E6   C=12.E6      FRIC=45       I 1 78 J 15 22
PROP S=4.E9   B=6.67E9   D=2300  T=9.E6    C=12.E6      FRIC=45       I 1 78 J 22 32
PROP S=2.2E9 B=3.67E9   D=1427 T=1.86E6 C=1.85E6   FRIC=30            I 1 78 J 12 14
PROP S=2.2E9 B=3.67E9  D=1427 T=1.86E6 C=1.85E6    FRIC=30            I 1 78 J 25 27
*PROP S=1.14E9 B=1.7E9    D=1109.80 T=.56E6 C=1.1E6 FRIC=35           I 1 78 J 17
*PROP S=3.06E9 B=3.9E9  D=1109.80 T=2.8E6  C=2.1E6  FRIC=35           I 1 78 J 19
*PROP S=4.E9   B=6.67E9 D=2300 T=9.E6   C=12.E6  FRIC=45               I 1 78 J 18
SET GRA 9.81
set large
set FLOW=OFF
FIX X  I 1
FIX X  J 1
FIX X  I 79
FIX Y  J 1
INI SYY -3.75E6 VAR 0 3.75E6
INI SXX -4.5E6 VAR 0 0.850E6
HIS NSTEP 10
HIS XDIS I 30 J 14
HIS YDIS I 30 J 14
HIS UNBAL I 1 J 1
MOD NULL              I  8 11 J 12 14
MOD NULL             I 24 27 J 12 14
MOD NULL             I 45 48 J 12 14
MOD NULL             I 66 69 J 12 14
MOD NULL             I  8 11 J 20 22
MOD NULL             I 24 27 j 20 22
MOD NULL             I 45 48 J 20 22
MOD NULL             I 66 69 J 20 22
*SOLVE
s 15000
```

```
**********************************************
*With developement only* Save as p3d150.2.sav
**********************************************
Save  D:\flac\project\p3d150.2dev.sav
******Split galleries 5m x 3m
******************OPENING OF SPLIT 1**********
MOD NULL I 17 18 J 12 14
MOD NULL I 17 18 J 20 22
*******************OPENING OF SPLIT 2**********
MOD NULL i 38 42 j 12 14
MOD NULL i 38 42 j 20 22
*******************OPENING OF SPLIT 3**********
MOD NULL i 59 60 j 12 14
MOD NULL i 59 60 j 20 22
*
*SOLVE
s=8000
Save  D:\flac\project\p3d150.2split.sav
MOD NULL I 54 69 J 12 14
MOD NULL I 54 69 J 20 22
*SOLVE
s=15000
SAVE D:\flac\project\p3d150.2EXP1.SAV
*****************For extraction of two pillars
**************EXTRACTION OF PILLAR 2
MOD NULL I 33 48 J 12 14
MOD NULL I 33 48 J 20 22
*********************************************************
****After extraction of  two pillars WITHOUT CABLES IN GOAF
********save as ncexp2C.sav
*SOLVE
s=15000
SAVE D:\flac\project\p3d150.2EXP2.SAV
**************************************************************
****** FOR EXTRACTION OF 2.5 PILLARS with cable bolts in goaf
MOD NULL I 17 27 J 12 14
MOD NULL I 17 27 J 20 22
*SOLVE
s=15000
***** *FOR 2.5 PILLARS EXTRACTION - SAVE AS NCEXP25C.SAV
SAVE D:\flac\project\p3d150.2EXP25C.SAV
***********************************************************
*****After judicious rob  and burst of rib 1****
MOD NULL I 49 53 J 12 14
MOD NULL I 49 53 J 20 22
*SOLVE
s=15000
***** FOR 2.5 PILLARS EXTRACTION - SAVE AS NCEXP25R.SAV
***********************************************************
SAVE D:\flac\project\p3d150.2EXP25R.SAV
```