FLOW BEHAVIOUR OF POND ASH SLURRY AND SHRINKAGE OF POND ASH STOWED MINE AREA

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

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

By

JYOTI PRAKASH SAHOO

111MN0399

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008
2011 - 2015

FLOW BEHAVIOUR OF POND ASH SLURRY AND SHRINKAGE OF POND ASH STOWED MINE AREA

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

BACHELOR OF TECHNOLOGY

IN

MINING ENGINEERING

By

JYOTI PRAKASH SAHOO

111MN0399

Under The Guidance Of

DR. SINGAM JAYANTHU

DEPARTMENT OF MINING ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY
ROURKELA-769008
2011 - 2015

National Institute of Technology

Rourkela

CERTIFICATE

This is certify that the thesis entitled "**FLOW BEHAVIOUR OF POND ASH SLURRY AND SHRINKAGE OF POND ASH STOWED MINE AREA**" submitted by Shri Jyoti Prakash Sahoo, Roll No.111MN0399 in partial fulfilment of the requirements for the award of Bachelor of Technology degree in Mining Engineering at the National Institute Of Technology, Rourkela is 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 other University/Institute for the award of any Degree or Diploma.

Date:18-MAY-2015

Dr.Singam Jayanthu

Department of Mining Engineering

National Institute 0f Technology Rourkela-769008

ACKNOWLEDGEMENT

In pursuit of this academic endeavour, I feel singularly fortunate. First and foremost, I express my sincere gratitude and indebtedness to Dr.S.Jayanthu, Professor of Department for allowing me to carry on the present topic “**FLOW BEHAVIOUR OF POND ASH SLURRY AND SHRINKAGE OF POND ASH STOWED MINE AREA”** and later on for his inspiring guidance, constructive criticism and valuable suggestions throughout this project work.

An assemblage of this nature would not be possible without reference to and inspiration from the works of others whose details are mentioned in reference section. I acknowledge my indebtedness to all of them. I sincerely thank to all my friends and research scholars in the department who have patiently extended all sorts of help for accomplishing this assignment.

Finally, I humbly bow my head with utmost gratitude before the God Almighty who always guided me all the way and without whom nothing could have been possible.

Date: 18-MAY-2015

JYOTI PRAKASH SAHOO
Department of Mining engineering,
National Institute of Technology
Rourkela – 769008

CONTENTS

ABSTRACT

Backfilling enables complete or around ninety percent extraction of coal from the seam and then filling the mine voids with mill tailings; sand or excavated stones etc. which provides additional ground support by constraining lateral deformation of surrounding coal pillars and roof. However the overall feasibility of the backfill operation with different materials has to be studied in detail.

The objective of this project is to evaluate the suitability of using pond-ash as backfill material over fly ash and sand in respect to shrinkage of the stowed area. The shrinkage study is done with the help of numerical modeling in FLAC of a mine KTK-5 where pond-ash stowing is going to be implemented. The physical properties like bulk modulus, shear modulus, cohesion, friction angle etc. were also found out through experiments which are required during the numerical modeling. Moreover an effort has also been made to develop comprehensive flow model using CFD and then use the model for predicting pressure drop, volume fraction etc. A 20m pipe with diameter of 20cm is modeled, through which flow is conducted where modeling and meshing is done using ANSYS Fluent. High viscosity fly and pond ash slurry with different concentrations up to 70% by weight of pond ash is passed and for each concentration different velocities are used and pressure drops is calculated.

MDD ranges from 1.07gm/cc to 1.27gm/cc. With increase in compaction energy MDD increases due to the closer packing of pond ash particles and OMC decreases from 38% to 28% approx. which might be due to the increase in moisture content leading to less friction between the particles and promoting compact packing with increase in compaction which in turn decreases voids and increase saturation limit. The settling rate for the sample is found to be around 30% with water-liquid (phase1) and pond-ash (phase2). Velocity of 3.5m/s of the paste are optimum with respect to pressure drop. The FLAC simulation yields factor of safety (FOS) after excavation of one pillar with no fill to be 1.5 whereas with pond ash fill it is 2.7. Similarly FOS after stowing with pond ash in the voids of two pillars was found to be 2.5 whereas without fill it was 1.2. After excavation of two and half pillars FOS was calculated to be 1.9 with pond ash fill and 1.0 without fill.

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Generation and utilization of fly ash as well as bottom ash has been thoroughly studied for quite a time and still continuing. Though there has been major advances in its effective and sustainable use, problems regarding its effectiveness in the back-filling of mine voids has manifold. With the increasing dependency on coal consumption for power generation and other purposes, proportionate amounts of ash is being generated as a by-product of coal combustion. Generation of 1 MW thermal power results in the generation of 1500 T fly ash and300 T bottom ash amounting to 1800 T in total. At present, approximately 570 MT of coal per annum is being consumed which in turn produced around more than 200 MT of fly ash per annum only (2013-2014). The generation of fly ash is expected to exceed 300 MT per annum by 2017. This suggests that a large area of land would be occupied which possess an imminent danger to the environment. Therefore it is more imperative that advanced technologies for gainful utilization and safe management of ash on sustainable basis should be adopted. Though continuous efforts are being made, yet it seems meager as compared to the amount of its generation. Utilization of ash is approx. 110 T i.e. 50% and rest is accumulating in the ponds successively. This by-product is largely collected from the smokestacks of coal run thermal plants, while bottom ash is expelled from the base of the furnace. Before, fly ash powder was for the most part discharged into the climate, however contamination control laws ordered in late decades now oblige that it be caught before discharge. The constituents though vary from different fly ash according to the coal, yet all fly ash remains incorporates considerable measures of silicon dioxide ($SiO2$) (both shapeless and crystalline) and calcium oxide (CaO).

Numerous sorts of ecological issues are connected with the stored fly ash, for example, land degradation and deterioration of air and water quality. The issue of putting away the fly ash remains makes impressive interest for area, along these lines putting weight on the accessible area .The ecological issues from the put away fly ash get exasperated under particular conditions. For example- amid hot and dry seasons under wind flow conditions, fly ash particles easily get suspended in the air raising serious health concerns. Amid the times of substantial precipitation overflow from the fly ash ponds can pollute the encompassing water bodies and agrarian lands.

On a global scale, recent studies in the area of mine void filling are primarily concerned with the utilization of mill tailings and to certain extent fly ash based, mixtures. A moderately new innovation, high fixation inlaying, empowers mining industry to think on the utilization of fly ash as underground refill material. The points of interest are tremendous. Jharia and Raniganj coalfields being the oldest in the nation had received unscientific mining amid pre-nationalization period. In almost many cases mining was directed without proper stowing and that had brought about serious issue in these two townships. Both these townships are experiencing extreme issues of subsidence. It is expected that with the advancement of this innovation it will be conceivable to take care of this recalcitrant issue. The issue of underground fire can likewise be controlled once this innovation is received. Because of overuse of sand for development industry and non-renewal of sand in the rivers because of development of dams at the up flow, availability of sand is meager. It is expected that it will be greatly hard to get a lot of sand for stowing reason in future. So the need of the hour is to search for optimum material to replace sand for backfilling purposes in mine. A survey conducted by CMRI indicates that there are about 25 power plants situated within a distance of 20 Km. of underground coal mines using sand as stowing material at different coalfields of India. These thermal power plants are delivering a colossal amount of ash-powder which can be utilized as another material that can be used for stowing. There are many similarities as well as differences of utilizing ash in place of sand as a stowing material. When this innovation of pond ash stowing is created with high concentration structure, it will be conceivable to get a modified rate of stowing which will inevitably build the coal extraction from depillaring boards.

The pervasive method of filling the mine voids is water powered (hydraulic) sand stowing in which sand water mixture is arranged at surface and is permitted to gravitate toward the underground void to be filled. The methodology of hydraulic sand stowing is naturally moderate and is damaged with other reasonable challenges like non-accessibility of satisfactory measure of sand, transportation of sand, extra pumping needed to manage stowing water, sticking of stowing pipes because of quick setting of sand, faster scraped area of pipes by sand, moderate stowing rate and so forth. While fly ash by virtue of its pozzolanic activity, may find applications but the pond ash is utilized in a limited way. The need of great importance is to create and make an innovation, which could guarantee high success rate of backfilling of mine void to meet the higher creation necessity. High concentration pond ash slurry transfer framework is such an innovation.

1.1 Specific Objective:

- A methodological and logical study of pond-ash slurry at high concentrations with the help of computational fluid dynamics as well as evaluate the flow characteristics of the same.
- The shrinkage study of the pond-ash stowed area by simulation of geo-mining conditions in KTK-5 mine and hence stability of the stowed area.

1.2 Methodology:

To achieve the goal of this study, the following steps have been carried out:

- Literature review: Different books, journals, reports as well as magazines were critically revised to enhance know-how about the generation, storage processes of ash in thermal power plants. Also read literature on different properties and factors that affect the flow behavior of the slurry followed by their confinement behavior leading to shrinkage problems.

- Sample collection: Samples were arranged from NTPC, Ramagundam.

- Data analysis: Experiments are conducted to analyze the properties of pond ash samples collected so that the same can be used for further analysis by simulation software.

- Fluent software (academic) of ANSYS was used for simulating the flow behavior of pond ash slurry. The software is provided by the institution with the key required. Moreover the stress distribution as well as displacement of the roof prior to backfilling as well as after backfilling has been modeled with the FLAC software provided by the department with the key required. The modeling has been done with three types of backfill materials i.e. pond ash, fly ash and sand.

CHAPTER – 2

LITERATURE REVIEW

1. **GENERATION**
2. **POND ASH AS BACKFILL MATERIAL**
3. **FLOW CHARACTERISTICS**
4. **SHRINKAGE STUDY**

2.0 LITERATURE REVIEW

The potential usage of large volume transfer systems for the inconceivable amounts of the fly ash produced in the nation is to use the material as filler in the deserted or in the dynamic mines, whether surface or underground. Because of the accommodation of getting to the troublesome transfer locales, furthermore because of coherence of the operations, water powered transport of the fly ash stands separated as practical and conceivably financial innovation. Accessibility of the fly cinder in the nearness of a mining site can make ideal conditions for its utilization as a fill medium.

2.1 Generation

Coal is the major source of energy (accounting for 60%). Hence to produce energy pulverized coal is generally combusted in a coal fired boiler. During this process, the volatile matter and carbon compounds burn off and the impurities such as clay bands, shale, quartz, feldspar and others mostly fuse and don't settle down usually. The fine grained powdery particulate matter known as fly ash then is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, bag houses, or mechanical collection devices such as cyclones. In general, there are three types of coal-fired boiler furnaces used in the electric utility industries which are referred to as dry-bottom boilers, wet-bottom boilers, and cyclone furnaces, of which the most common type of coal burning furnace is the dry-bottom furnace.

At the point when pounded coal of size 2mm to 50mm is blazed in a dry-ash, dry-bottom boiler, around 80 percent of all the slag leaves the heater as fly ash, entrained in the vent gas. At the point when pummeled coal is smoldered in a wet-base (or slag-tap) heater, as much as 50 percent of the powder is held in the heater, with the other half being entrained in the vent gas. Whereas in a cyclone furnace, where pulverized coal is utilized as a fuel, 70 to 80 percent of the ash is held as evaporator slag and just 20 to 30 percent leaves the heater as dry powder in the flue gas. Pond ash is the by-product of thermal power plants, which has no further use in the plant and its transfer is a significant issue from a natural perspective furthermore it obliges a considerable measure of transfer zones. There are two sorts of slag created by thermal power plants, viz. (1) fly ash, (2) bottom ash. Fly ash is gathered by mechanical or electrostatic precipitators from the vent gasses of force plant; while, bottom ash is gathered from the base of the boilers. At the point when these two sorts of ash, combined, are transported as slurry and put away in the ash ponds, the storage is called as pond-ash in which former constitutes of 80% and that of latter is 20%. Flow diagram of ash production in a thermal power plant with dry-bottom coal-fired utility boiler operation is as shown

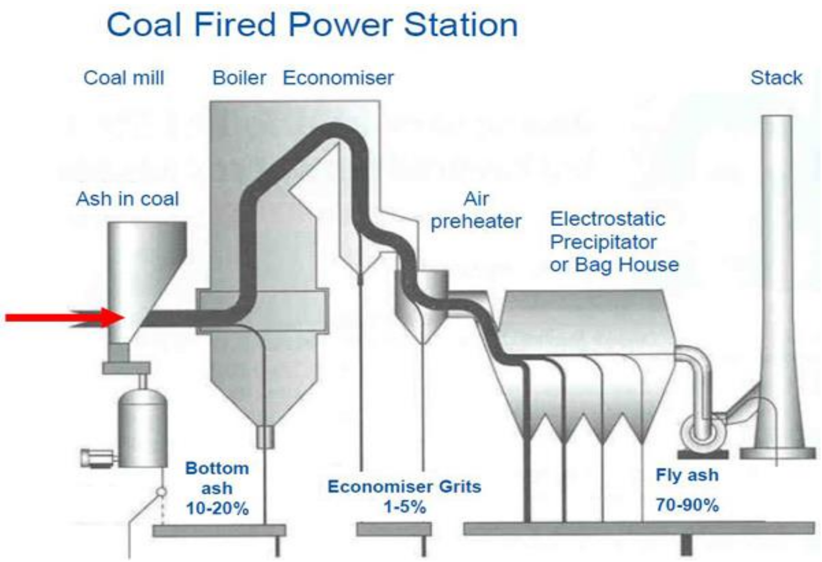


Figure 1: Flow Diagram of Ash Production In Thermal Power Plants

2.2 Pond ash as filling material

The different constituents of the back fill using pond ash are as follows:-

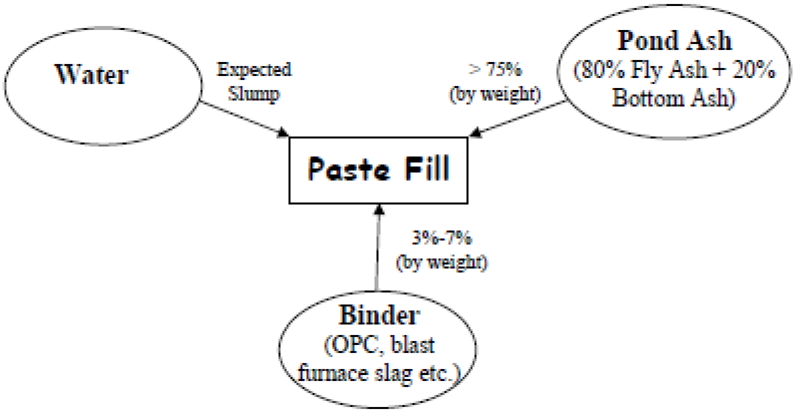


Figure 2: Composition of Paste Fill With Pond Ash

Paste backfill of pond ash has many advantages over the conventional hydraulic sand stowing which are as follows:-

- With paste backfilling dewatering cost of the mine will be reduced significantly as minimal dewatering is required and moreover quick solidification/ setting can also be achieved owing to the pozzolanic characteristics of the ash.
- Since mine voids will be used for filling, surface disposal of coal ash can be reduced exceptionally. Moreover the ecological issues of contamination of drinking water due to leeching of minerals to the ground water will not pose as a threat.
- Paste backfill is denser than sand which is used in conventional stowing resulting in higher confined strength which means there would be no surface storage requirements except the bunker and the ash are returned underground with ease.
- The system is well equipped to handle bulk slurry for stowing resulting in swift filling of the voids with no delay.
- The system has its effectiveness in situations where hydraulic stowing is not cost effective owing to the unfavorable hydraulic gradient.
- Difficulties faced due to housekeeping and wear/corrosion of mine dewatering pumps are more likely with the conventional stowing because of the drainage of fines in backfill operations which is non-existent with paste backfill.
- Due to the quick setting time of paste backfill shorter fill cycle can be achieved which remarkably reduces the number of active work face required.
- Less free water will definitely reduce leachate generation and less available oxygen as a result of higher degree of saturation.
- Moreover less water content of the paste backfill enables less preparatory work prior to the back-filling operations.

The successful implementation of this pond-ash backfill scheme will result into number of positive outcomes leading to:

- With the inclusion of high concentration ash slurry disposal system, problems of ash disposal and challenges imposed as sustainable utilization of high quantities of ash produced by thermal power plants can be easily rooted out.
- Relieving the land from the ash storage and making it available for judicious use.

- Due to environment-friendly nature of the disposal and stowing system, it eliminates all major environmental pollution arising due to the ash disposal including the contamination of the ground water table.
- Since there is a reduction of ash disposal system losses incurring due to power is also reduced.
- Low water consumption of this system in comparison with the conventional hydraulic system will eliminate the nuisances of dewatering the stowing water.
- The high density of the paste fill will enable high rate of settling and hence compaction will be least. This will in turn result in judicious packing of the void providing more support to the overlying strata from getting separated effectively.
- Conventional sand stowing is an inherently slow process which turns into a constraint for bulk production which is tackled by the capability of handling bulk slurry for stowing by the high concentration disposal system.
- Due to less wear and tear of the sowing pipes will lead to less maintenance leading to less man-power and hence reduced costs.
- Moreover less quantity of water usage will not lead to halting of the stowing process due to bursting of barricades as well as transporting pipelines etc.
- Availability of sand for hydraulic stowing is depleting gradually. Although it is inert and cheap but due to its meager availability and adverse environmental issues procurement of adequate amount of sand is an uphill task.

2.3 Characteristics of Pond Ash Slurry

2.3.1 Settling properties:

Settling rates define the ease with which solid-liquid separation happens in slurries during filling activity, and the experiments also depict the ways of assessing the recycled water quality.

2.3.2 Process of Transportation of Pond Ash:

Much consideration has been paid in late decades for the hydraulic powered transportation of solids in the pipelines because of a few contemplations. The upsides of the strategy incorporate lessened dust due to air, material handling on permanent basis, effortlessly automation process and so forth etc. The accessibility of water in mining ranges and the specialized effortlessness of the methodology, have led to the pretty much standard practice of water driven transportation of sand or such comparable medium for filling of voids in underground mines.

2.3.3 Slurry Flow Behavior:

At the point when a solid –liquid (slurry) mixture is passed on through a channel, distinctive states of flow may be experienced relying upon the properties of the solids, passed on fluid, and the attributes of the pipeline. The distinctive flow conditions of slurry are homogeneous, intermediate, saltation flow. As the name recommends, the flow is homogeneous if the different properties of the suspensions (like density, concentration of solid, viscosity) don't change over the pathway. Homogeneous flow of suspension is conceivable if the accompanying conditions are fulfilled:

- The solid constituents must be light as well as finely dispersed.
- The flow rate of slurry should be high.
- The concentration of the solid should be high.

For homogeneous flow it is key to have the terminal settling speed of the particles as little as could be expected under the circumstances so that the fixation inclinations don't exist.

Homogeneous suspensions act like single segment liquids and their flow can be depicted utilizing a suitable rheological model. This homogeneous flow can happen either in laminar mode or in turbulent mode. The move from laminar to turbulent mode is shown by the deviation in the slope of the pressure drop -flow rate structure. In real practice, no particulate suspension of interest carries on like a homogeneous mixture at all flow speeds. It means that when the mean flow speed Vm is sufficiently high then all the particles are completely suspended and efficiently circulated crosswise over segment of the pathway. This is called the “symmetric suspension regime”. At these speeds, the turbulent and the other lifting strengths are adequate to hold all the particles under suspension and keep them from sliding over the wall of the pipe. As slurry speed (and consequently the force of turbulence and lift forces) is diminished, the settling propensity of the particles causes a bending of the profile and flow will get to be topsy-turvy. Solid particles’ concentration will be more at the base of the pipeline. This is responsible in the distortion of the speed profile with mixture speeds being more at top half of the pipeline as compare to the lesser part of the pipeline. This distortion in both the concentration profile as well as in speed profile will be enhanced with reduction in mixture speed. In this manner the flow will get to be more heterogeneous.

At the speeds underneath VM2 particles has a tendency to amass at the base of the pipe, first in the form of dunes and after that as constant ‘moving bed'. The dunes or the bed moves at an impressively lower speed with that of fluid or strong particles above it. The particles at the highest point of the bed are made to roll and tumble by the shear strength created by the flow above. It is clear that the particles in the flow above moving bed will be much lower when contrasted with the normal amassing of solids. The mixture speeds these upper locales are sufficiently high to keep the particles in suspension (Seshadri 1997).

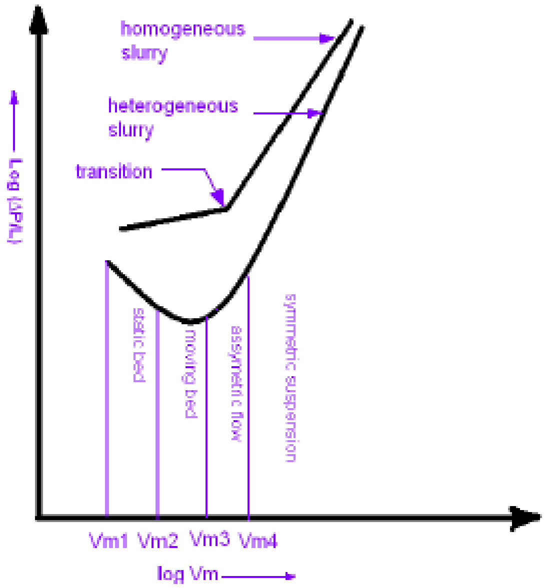


Figure 3: Flow Regions In Slurry Transportation

As the slurry speed is further lessened (VM<VM3) the lowermost particles of the bed get to be stagnant and thickening of the bed results. The bed movement happens basically by the highest particles tumbling more than each other (saltation). This locale of flow is called ‘stationary bed' and flow will be to some degree precarious. Underneath a mixture speed of VM4 the bed up and high weight inclination will be a necessary to control flow. When the bed begins framing beneath a speed, VM2 the pressure gradient would demonstrate an inversion and the pressure increments with diminishing mixture speed bringing about the chocking of the pipeline (Seshadri1997).

Above said flow conduct would be entirely substantial when the size of the particles are almost equal. However in applications, for example, stowing and filling the particulate size transported shifts over a wide range. Henceforth, at given mixture speed the smallest constituents may be homogeneously disseminated over the pipeline cross-segment, while, concentration contour would be conspicuous for the bigger particles. Likewise the biggest estimated particles would have a tendency to settle first while the others are still under suspension. Accordingly, for given mixture if all the particles are in suspension at that point the concentration profile would be uniform for minute size, though it has a tendency to be gradually, non-uniform as the diameter of the particles increments. This would make the suspension flow close to the base of the pipe progressively coarser when contrasted with that flow at the top of the same. As the mixture speed decreases all the particles with bigger diameter will constitute the lower base of the pipeline. Consequently, for multisided particulate suspensions a blend of homogenous and heterogeneous flow will be observed. Moreover, the changeover speeds (VM1 to VM4) are not obviously characterized and the distinctive flow districts are not plainly discernable (Seshadri. 1997).

Inside the transition zone for heterogeneous and saltation medium, there is an exceptional speed comparing to least head loss in the pipeline, underneath which the settling of solids will happen, yet above which, the flow is homogeneous. This speed is the critical speed.VC (Kokpmar and Gogus. 2001).The critical speed for particular solids concentration within the slurry flow corresponds to the minimal losses in frictional pressure. The movement of the slurry at this speed brings about optimized power for the transportation framework and in the meantime guarantees long life of pipe because of reduction in wear. It is practically difficult to determine general relationships for the estimation of different transition speeds in slurries of diverse materials. This is on account of it is not possible to consider the impact of such a variety of parameters which change from one slurry type to another. The fine particles would build up the viscosity of the slurry bringing about more imperviousness to settling of bigger particles. Hence, the particles in the slurry may be completely suspended even at moderate mixture speeds, while without fine particles the bigger particles would have settled down. The terminal settling speed of the suspended particles as in the model by Kokpmar and Gogus (2001), is considered for the formulation of critical speed of the slurry.

$$\frac{V}{gD}=0.055\left(\frac{d}{D}\right)^{-0.6}C_V^{0.27}(S-1)^{0.07}\left[\frac{Pf*Wm*ds}{\mu f}\right]^{0.30} \qquad \text{----------------------------- (1)}$$

where

V = man critical flow velocity of slurry (m/s);
C = concentration of solid materials by volume;
D = Pipe diameter (m);
D_s = mean particle diameter (m);
S = specific gravity;
W_m= particle settling velocity in slurry (m/s);
uf = dynamic viscosity of fluid (kg/m-s);
Pf = density of fluid (kg/m^3);
G = gravitational acc. (m/s^2).

In the Georgia Iron Works (GIW) pipeline plan manual Addie (1982) demonstrated that the flow of a fluid mixture through a pipe is complex process with the flow attributes and ensuing pipe wall friction depending on particle shape and size, concentration of solids, density, mean speed, incline of the pipeline et cetera .Addie (1982).distinguished slurries by settling and non-settling sorts relying upon the settling speed of the particulates in the slurry. Particles with settling speeds higher than 1.5 mm/s in the slurry are categorized as settling slurries, whereas particles have settling speeds underneath 1.5 mm/s in the slurry were non-settling slurries.

Non-settling slurries conveyed through pipe have a uniform dissemination of particles over the flow segment and show axisymmetric speed dissemination. In this paper systems to gauge the gradients of frictional pressure for the non-settling slurries under laminar and turbulent flow environment are displayed. The methods consider tube sort viscometer estimations and estimation pseudo-fluid (slurry) densities. It might be for the most part expressed that, no dependable strategy exists for the estimation of the flow properties of non-settling slurries in view of estimations from the properties of the solids and fluid. Practically speaking, slurry conveyance of non-settling slurries in laminar flow section is eliminated fundamentally since bigger particles may settle to the base of the pipe making a stationary bed. Much of the time, frameworks are intended to run at speeds excess to the transition phase speeds (Addle, 1982).

Slurry of settling type in a pipe ordinarily flows as a heterogeneous mixture in which some solid particles are conveyed as suspended burden and the leftovers are conveyed as bed burden. The bed burden or stratification ratio (R), which is the proportion of the bed burden transport to aggregate transport, is a helpful parameter to describe the flow conditions. Since the instrument of suspension and turbulence, is a component of mean speed in the pipe, the value of R is likewise an element of Vm. At an adequately high mixture speed, the majority of the strong particles will be passed on as suspended burden on the other hand as a pseudo homogeneous suspension for which R=O. At slower speeds the solid particles has a tendency to settle towards the base of the pipeline with the fact that some are bed burden transport and minimal extra resistance coming about because of suspended—burden transport. The lower cap of the heterogeneous suspension happens when the speed is lessened to the deposit speed and the solids begin to shape a stationary bed. A little stationary bed is innocuous, however there is no sense to waste a piece of the flow cross segment with a stationary bed. In order to block a stationary bed, pipelines are composed so that Vm is greater than deposit speed. Settling slurries with diffusive pumps as prime movers, the transport speed is regularly well over the deposit speed with a specific end goal to working speed. The speed Uu , at the limit of turbulent suspension is (Addle, 1982)

$$Uu = 0.6Vt\sqrt{\frac{8}{ft}}e45(d/D) \qquad \text{------------------------------ (2)}$$

where

V_t= terminal settling velocity;
ft = friction factor of fluid flowing at velocity, V_m;
d = particle diameter;
D = internal pipe diameter.

2.3.4 PASTE FLOW BEHAVIOR:

The term paste is for alluding to slurries which can be pumped and have consistency of a quantifiable slump. Paste is high density uniform material of such mineralogical and size make up, that will drain just minor amounts of water when very still, encounter least isolation, and can be moved in a pipeline at line speeds well beneath that of critical speeds for comparable materials at lower slurry densities. Paste can stay in a pipeline for quite a period of time when pozzolanic materials are not present, without influencing the resumption of conveying processes. Paste fill operations are instantly getting to be more normal and can offer a few focal points over conventional systems for refilling and surface transfer. Every application requires cautious assessment to discover the suitability to nearby conditions following the paste formula, plant configuration and dissemination frameworks are all that much reliant on the paste attributes and mine necessities. Available literature on paste flow nature is basically constrained to that of uses of plant tailings, mine waste and cement and sand total fills. In the meantime mot much reported data exists on the utilization of fly ash remains in paste flow applications.

Cooke (2001) sketched out typical pipeline gradients of pressure that may be experienced amid the transportation of paste mixtures for two unique solids concentration. A strategy to focus the pipeline pressure slopes under laminar paste flow conditions utilizing the pipe wall shear stress was sketched out in this paper. Cooke additionally demonstrated that no accurate answer for the turbulent flow of paste was conceivable and that just approximate evaluation could be made in view of pseudo liquid as close estimation for the paste. Paste frameworks when all is said in done are accounted for to work in laminar flow. The paste flow outline framework should consider least pressure inclination as and design element to keep the settling of paste dissimilar to the base working speed which is an element prerequisite for slurry transportation (Cooke, 2001). Loop tests are prescribed by author for findings about the nature of paste flow. The tests could be directed utilizing little scale pipe loops (20 to 50 mm) in a lab, or full scale loops at the mine site or at another built test loop. The benefits of little scale tests are fundamentally lower material necessity, lower expense, more prominent instrumentation exactness and accessibility of deliberately controlled exploratory conditions. The paper basically gives a judicious premise for breaking down paste flows in light of innovation produced for settled slurries. The pseudo shear outline gives a straightforward method to scaling test loop information without obliging complex rheological portrayal as reported by Cooke (2001).

The investigation of Vickrey and Boldt (1989), showed that paste with low slumps has requirement of higher pumping pressure, while the fill with high slumps had a more prominent propensity to bring about pounding at the pump, furthermore the high slump pastes settled when left stagnant in the pipe line. These perceptions were made amid pump tests in loop utilizing established and un-cemented pastes with slumps qualities extending from 10.8 to 17.8 cm taking into account the 30.5 cm standard slump cone test. Tenbergen (2000), experimented over specific viewpoints and attributes of paste stowing operation. He researched over the paste flow nature of industrial tailings and final material also, exhibited the loop test results as far as concentration of solid, loss of pressure, and compressive quality. It was perceived that the slump quality was level more than the solids content in deciding flow behavior, and then pressure losses incurred during the conveyance resulting from low slump fillings.

2.4 SHRINKAGE STUDY

There is limited literature found on the shrinkage of the backfilled area in stowing operations. After the filling of the mine voids using paste fill, as the fill loses moisture either in its natural environment or by artificial means. Sometimes it changes from liquid state to plastic state to semi-solid state and then to solid state. Hence the volume is also reduced by the decrease in water content. But, at a particular limit the moisture reduction causes no further volume change. The most important concept of backfill support is that the fill itself doesn’t support the overburden. The additional strength that the fill transmits to the pillars is imparted as a horizontal pressure along the sides of the pillars. The resultant increase in strength is due to the confinement provided by the backfill. The weight of the fill itself provides some lateral resistance to the pillars. However, the magnitude of that resistance, even for strong, dense fills, would be too small to have any effect on the overall strength of the pillar. An increase in the horizontal pressure exerted by the backfill is necessary and can occur by using a cohesive fill and/or by applying a surcharge load to the fill. The cohesion of the fill is dependent on its properties and mix design while any surcharging loading will be a result of roof and pillar deformations. As the overlying strata deforms into the fill, the lateral pressure exerted by the fill increases by an amount equal to the surcharge load multiplied by an earth pressure coefficient.

The backfill since is hydraulically transported or high concentration slurry disposal (HCSD) has some quantity of dampness in it, and due to this the excess water is drained out leaving behind the high density solid particulates. The particular issues connected with this process that are tended to in this paper incorporate the loss of solid particles entrained in the excess water, the rate of quality increase of the backfill, and the post-arrangement shrinkage of the stowed material.

Since the prime capacity of backfill is to oppose subsidence of a mined-out stope, it is required for the stowed material to be in close physical contact with the hang wall at all times. Drainage of the water from the stowed area results in the consolidation of the backfill in its own area and reduction in the volume. This in turn leads to the formation of gaps between the hang wall and stowed area. It is clearly of little usage selecting stowing parameters so that losses in solids concentration are decreased and immediate stability is provided to the arrangement, if the post – deposition shrinkage of the fillings is vast. It is vital that the starting gap between the fillings and the hang wall is minimized (ideally killed) to give backing to the stone mass encompassing the stope as not long after exhuming as could be expected under the circumstances.

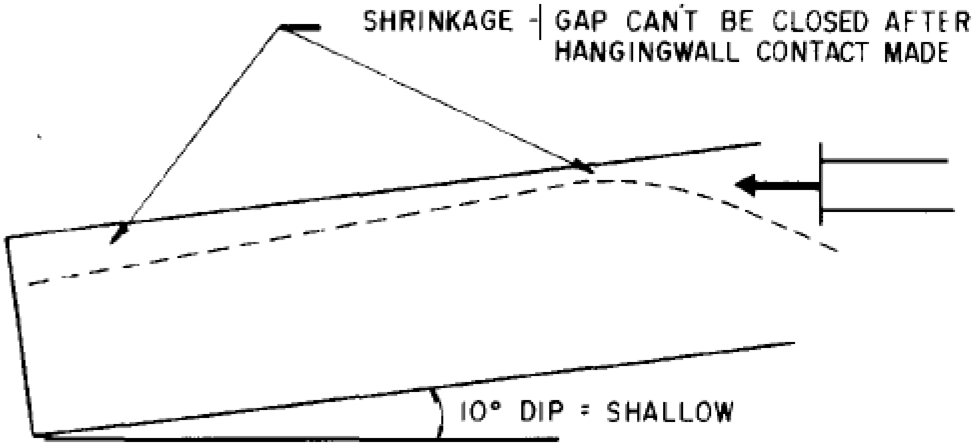


Figure 4: Shrinkage Observed At Hanging Wall

The reason a gap develops between the hanging wall and the backfill is that, as the backfill drains and consolidates under its own weight, it decreases in volume. This decrease in volume can be reduced by, *inter alia,* depositing the backfill at as high a density as possible, or depositing it at a slow rate in order to achieve as much consolidation during the filling process as possible. From the three backfills illustrated in Figure, field observations showed that problems of shrinkage did not occur if the dip angle of the stope exceeded about 15 degrees. This was because, for larger dip angles, the backfill tended to slump into any gap that may have formed, as illustrated in Figure 17, irrespective of the slurry density. For dip angles of less than 15 degrees, no slumping occurred, and the gaps that did open tended to remain open. It was extremely difficult to maintain complete contact between the backfill and hanging wall even immediately after the deposition had been completed.

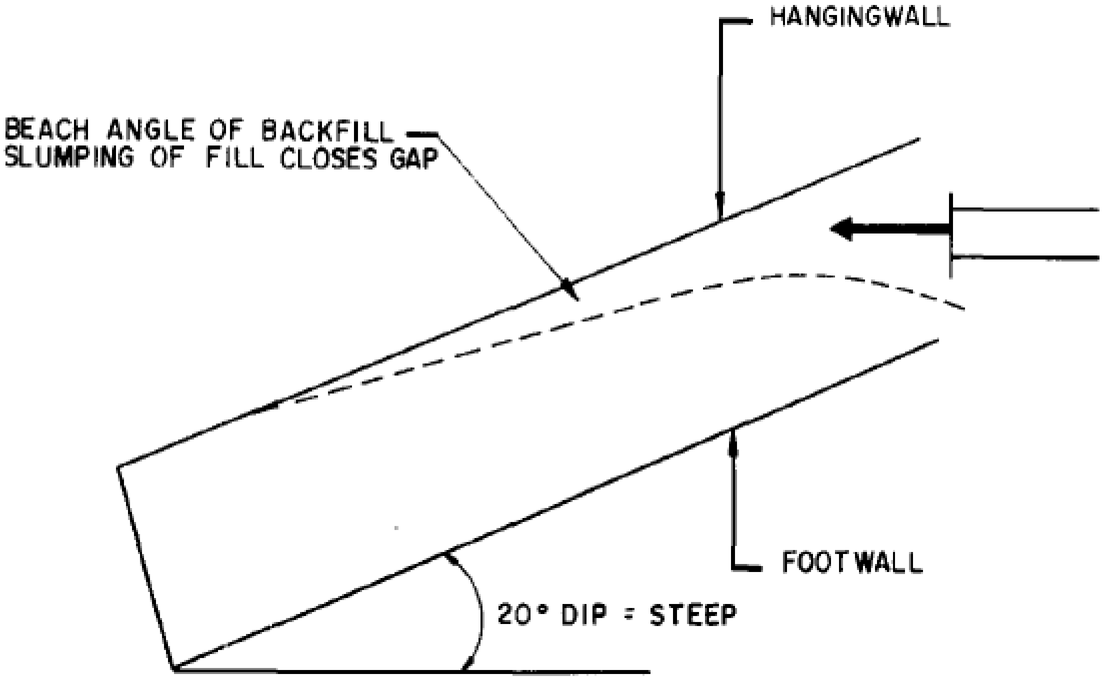


Figure 5: Shrinkage Observed At Hanging Wall

CHAPTER – 3

GEO MINING CONDITIONS OF THE MINE

3.1 GEOMINING CONDITIONS- KTK 5

The gradient of these coal seams varies from 1 in 2.8 to 1 in 3.3 (dip of 24o to 14o). Strike of the formations is NW-SE, and dip direction is NE. The width of the gate roadways to be developed in the four seams will be 4.8 m, and the height of the gate roadways will be maximum 3 m. The area is devoid of any faults or major structural disturbances.

Table 1: Borehole Data of The Mine

Strata/Seam	Lithology	Thickness Range(m)
Rock parting	Grey white sandstone and clay shale	5to16
1BSeam	**Coal and shaly coal**	-
Rock parting	Grey white sandstone with shale, clay, and thin coal bands	3to15
1ASeam	**Coal witha0.8m thick Carbonaceous clay bed at the top**	**1.24to2.54**
Rock parting	Grey white sandstone	26to35
1Seam	**Coal with occasional shale bands**	**1.58to3.44**
Rock parting	Grey white sandstone, shale, Carbonaceous shale and coal bands	3to28
2Seam	**Coal and shaly coal**	**1.41to3.6**
Rock parting	Grey white sandstone	7to32
3BSeam	**Coal**	**0.16to1.59**
Rock parting	Grey white sandstone	9to25
3ASeam	**Coal**	**0.1to1.24**
Rock parting	Grey white sandstone	5to18
3Seam	**Coal**	**2.0to3.9**
Rock parting	Grey white sandstone	10to19

Table 2: Seam and Roof Properties In The Mine

Strata	Roof of 1ASeam	Roof of 1Seam	Roof of 2Seam	Roof of 3Seam
Immediate roof/rock type	Coal/Carbo-nacreous Clay	Inter-bedded fg to cg Sandstone	Shaly Coal/ Sandstone	Coal/ Sandstone
Density(g/cc)	2-2.5	1.86-2.45	2-2.67	2.-2.75
Compressive Strength(kg/cm^2)	83-403	49-444	57-576	67-459
Tensile Strength(kg/cm^2)	9-54	2.7-45	6.8-58	6.5-43
Shear Strength(kg/cm^2)	22-107	9-98.5	14-132	15-102
Young's Modulus(x10^5 kg/cm^2)	0.30-0.86	0.19-0.94	0.20-1.19	0.22-0.97
Poisson's Ratio	—	7.7	-	0.1-7.7
Porosity (%)	—	10.6-11.7	9.8-12.2	8.2-14.5
P-Wave Velocity (m/sec)	—	2885-3477	2241.5-3456	2580-4101
S-Wave Velocity (m/sec)	—	1755-2021	1454.5-1928	1675.5-2110
Triaxial Cohesion (MPa)	—	7.6-11.5	-	2.3-9.6
Triaxial Friction Angle	—	31.68-40.55	-	34.36-59.88
Impact Strength Index	47-53	18-60	47-56	44.5-54
Protodyakonov Index	0.4-1.8	0.1-2	0.15-2.6	0.2-2

CHAPTER – 4

EXPERIMENTAL INVESTIGATION

1. **SAMPLE COLLECTION**
2. **PHYSICAL and CHEMICAL PARAMETERS OF POND ASH**
3. **DETERMINATION OF INDEX PROPERTIES**
4. **DETERMINATION OF ENGINEERING PROPERTIES**

4.1 Sample Collection:

The sample collection of fly ash, bottom ash and pond ash differs from each other because of their formation at different sites. In the power plant fly ash and bottom ash are generated and hence samples can be taken directly from discharge points. There is provision in most mines for collection of samples via a sampling pipe provided at their respective discharge point. Samples for pond ash are generally collected from the ash ponds where both fly ash and bottom ash are dumped.

Sample from NTPC, Ramagundam

- The sample was collected from the NTPC power plant from where it will be utilized as stowing material in ktk-5 underground mine.
- The sample was collected in sacks and immediately wrapped to avoid addition of moisture.
- The sample was then transported by suitable means and stored in dry place kept away from sunlight.
- The sample was oven dried at the temperature of 108± 2degrees. Further the material for the experimental work was taken which passed through the sieve of 2mm size.

4.2 Physical parameters of pond ash:

Table 3: Physical Parameters of Pond Ash

Parameter	Value
Shape	Sub-rounded
Color	Light grey
Uniformity co-efficient	4.65
Co-efficient of curvature	0.84
Plasticity index	Non-plastic

4.3 Chemical Parameters:

Table 4: Chemical Parameters of The Pond Ash

Parameter	Value (%)
SiO_2	59-61
Al_2O_3	28-28.8
Fe_2O_3	2.7-5.52
Na_2O	0.24-0.50
K_2O	1.26-1.76
CaO	0.7-1
MgO	1.40-1.90
LOI	0.5-2.5

4.4 Determination of Index Properties:

1. **Specific gravity test (IS 2720 (III/Sec-I):1980**

The specific gravity of pond ash was calculated by density bottle as illustrated in table

Table 5: Calculation of Specific Gravity

Mass of bottle	99.04	103.1	115.6
Mass of bottle + ash	149.04	153.1	165.6
Mass of bottle + ash + water	376.95	381.01	392.96
Mass of bottle + water	354.03	358.12	370.04
Specific Gravity	1.846	1.844	1.846

2. **Grain Size distribution (IS 2720 (IV):1985)**

Pond ash comprises of coarse as well as fine particles. Sieve analysis was performed for coarser particle whereas hydrometer for the finer particle. Co-efficient of uniformity and co-efficient of curvature were calculated using the formulae:

Co-efficient of uniformity, $C_u = D_{60}/D_{10}$

Co-efficient of curvature, $C_v = (D_{30})^2/(D_{60}*D_{10})$

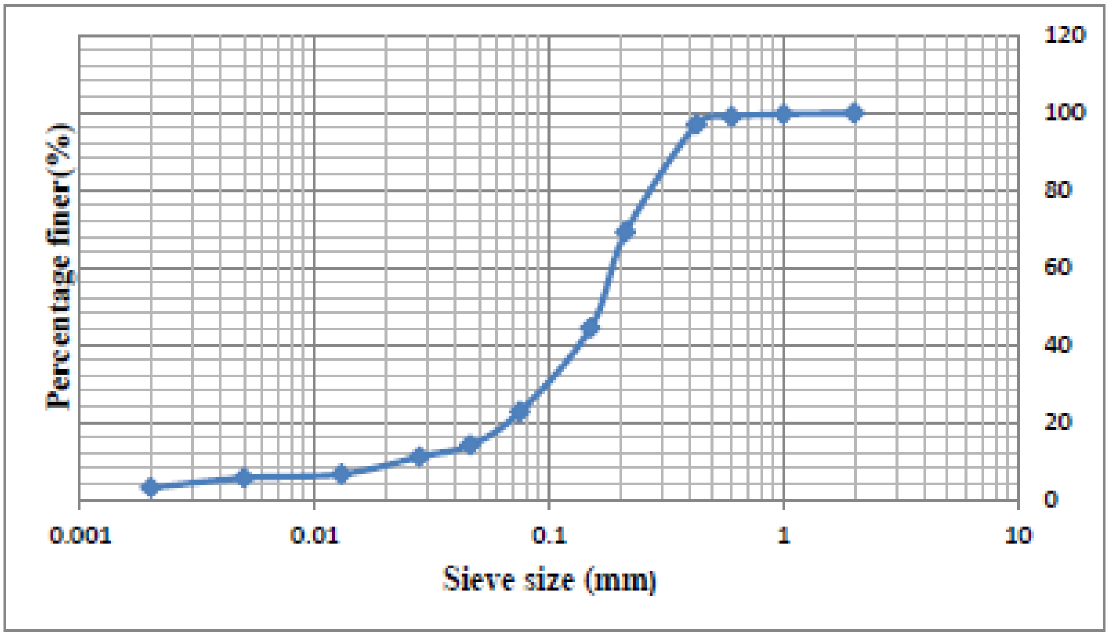


Figure 6: Grain Size Distribution

4.5 Determination of Engineering Properties:

1. **Moisture content and dry density through compaction tests (IS 2720 (VII):1980**)

Compaction tests are generally used to determine moisture content-dry density relationship of soil. In light compaction test pond ash at different water content was compacted in the mould in three layers with 25 blows in each layer given by a rammer of 2.6 kg with a drop of 310mm. in case of heavy compaction test pond ash at different water content was compacted in the mould in five layers with 25 blows in each layer given by a rammer of 4.5 kg with a fall of 450mm. From which OMC and MDD values were found out. Compaction tests were carried out for different compaction energy by increasing or decreasing number of blows given by rammer and presented in table:

Table 6: OMC and MDD after Compaction Tests

Sl. No	Compaction Energy, E(KJ/cm^3)	OMC (%)	MDD (gm/cc)
01	3639	38.82	1.09
02	6065	35.91	1.10
03	15223	31.38	1.16
04	27260	28.30	1.24
05	28444	28.18	1.26
06	35554	28.09	1.27

2. Shear parameters through Direct Shear Test (IS 2720 (XIII):1986)

Specimens of size 60x60x24 were tested in a 60mm square and 50mm deep shear box which is divided into two parts horizontally, with suitable spacing screws at normal stresses of 25 to 1000KPa and sheared at a rate of 1.25mm/minute. The peak friction angle and cohesion values were found for the different compactive efforts.

Table 7: Shear Parameters After Direct Shear Tests

Sl. No	Compactive effort (KJ/cm^3)	Dry density (gm/cc)	Moisture content (%)	Cohesion(C) (Kg/cm^2)	Friction angle (degree)
01	3639	1.09	38.82	0.153	21.9
02	6065	1.1	35.91	0.105	20.81
03	15223	1.16	31.38	0.116	21.8
04	27260	1.24	28.30	0.116	23.94
05	28444	1.26	28.12	0.079	20.81
06	35554	1.27	28.09	0.100	23.75

3. Unconfined compressive strength through unconfined compressive tests (IS 2720(X):1991)

This test was performed to determine unconfined compressive strength of pond ash. Sample was prepared at MDD and OMC. Then it was filled in the split mould of 5cm dia and 10cm height and compressed until failure. Sample was extracted by sample ejector. Then the sample was tested in a compression testing machine. A graph was plotted between stress vs. strain. From which UCS value was found out. Unconfined compression test was carried out for the soil samples at light compaction at light compaction density and heavy compaction density. Moreover the lateral strain was also measured by the instrument which was later used to find poison's ratio.

Table 8: Unconfined Compressive Strength After Unconfined Compressive Tests

Sl. No	Compaction energy (kg-cm)	Compressive strength (N/cm^2)
01	3639	0.112
02	6065	0.471
03	15223	0.589
04	27260	0.952
05	28444	1.010
06	35554	1.167

Table 9: Changes in Compressive Strength After Change in Moisture Content

Sl. No	Experiment Type	Dry density (gm/cc)	Moisture content (%)	Compressive strength (N/cm^2)
01	Standard proc. Data	1.1	35.91+10	0.158
02	Standard proc. Data	1.1	35.91 -10	0.7

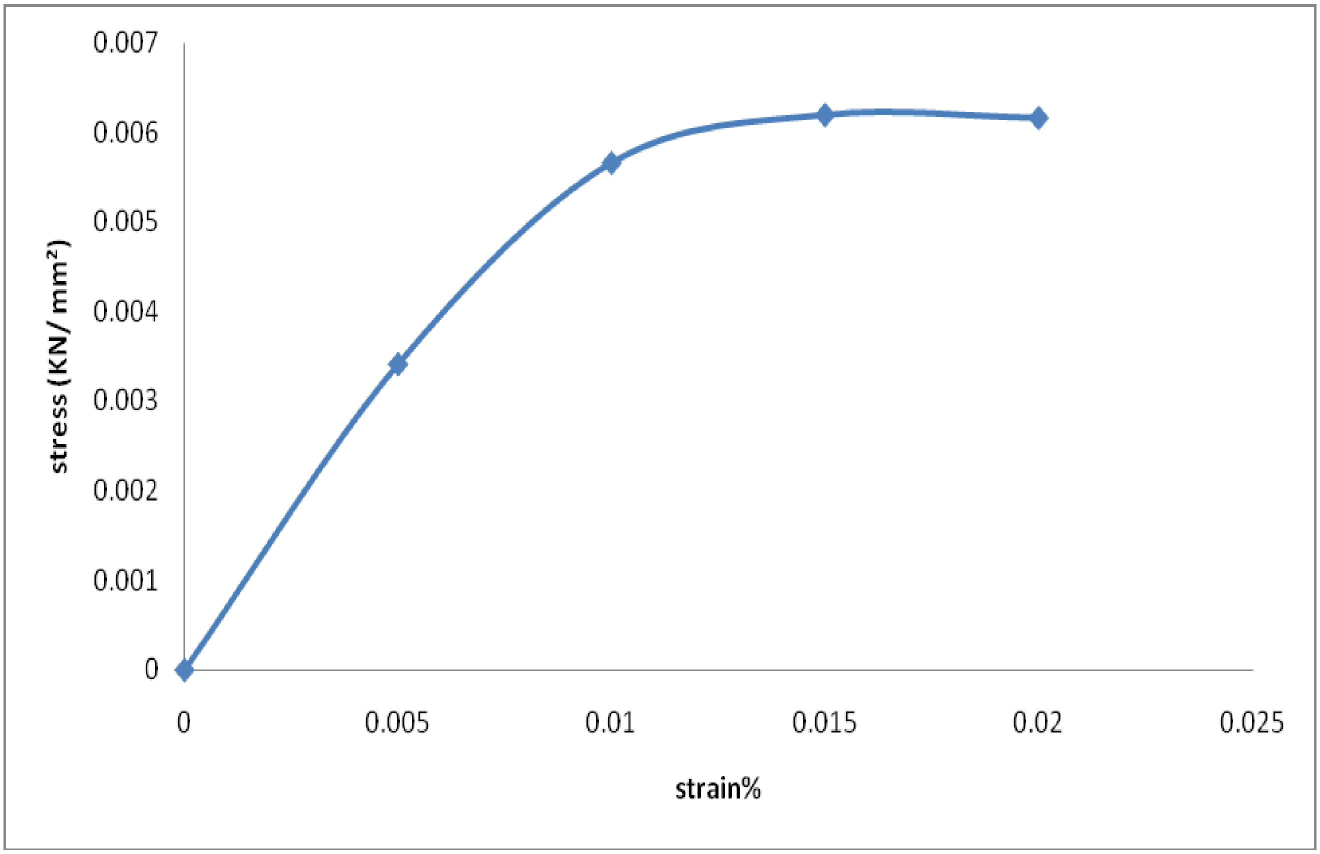


FIGURE 7: STRESS VS STRAIN GRAPH

Chapter -5

NUMERICAL MODELLING

1. ANSYS FLUENT FOR FLOW BEHAVIOR STUDIES
2. ITASCA FLAC FOR SHRINKAGE STUDIES

5.1ANSYS FLUENT

Overview:

ANSYS Fluent is a state-of-the-art computer program for modeling fluid flow, heat transfer, and chemical reactions in complex geometries.

ANSYS Fluent is written in the C computer language and makes full use of the flexibility and power offered by the language. Consequently, true dynamic memory allocation, efficient data structures, and flexible solver control are all possible. In addition, ANSYS Fluent uses a client/server architecture, which enables it to run as separate simultaneous processes on client desktop workstations and powerful computer servers. This architecture allows for efficient execution, interactive control, and complete flexibility between different types of machines or operating systems.

ANSYS Fluent provides complete mesh flexibility, including the ability to solve the flow problems using unstructured meshes that can be generated about complex geometries with relative ease. Supported mesh types include 2D triangular/quadrilateral, 3D tetrahedral/hexahedral/pyramid/wedge/polyhedral, and mixed (hybrid) meshes. ANSYS Fluent also enables to refine or coarsen the mesh based on the flow solution.

Fluent allows simulating the following:

- 2D planar, 2D axisymmetric, 2D axisymmetric with swirl (rotationally symmetric), and 3D flow
- Flows on quadrilateral, triangular, hexahedral (brick), tetrahedral, wedge, pyramid, polyhedral, and mixed element meshes
- Steady-state or transient flows
- Incompressible or compressible flows, including all speed regimes (low subsonic, transonic, supersonic, and hypersonic flows)
- Inviscid, laminar, and turbulent flows
- Newtonian or non-Newtonian flows
- Ideal or real gases
- Heat transfer, including forced, natural, and mixed convection, conjugate (solid/fluid) heat transfer, and radiation
- Chemical species mixing and reaction, including homogeneous and heterogeneous combustion models and surface deposition/reaction models

- Free surface and multiphase models for gas-liquid, gas-solid, and liquid-solid flows
- Lagrangian trajectory calculations for dispersed phase (particles/droplets/bubbles), including coupling with continuous phase and spray modeling
- Cavitation model simulations
- Melting/solidification applications using the phase change model
- Porous media with non-isotropic permeability, inertial resistance, solid heat conduction, and porous-face pressure jump conditions
- Lumped parameter models for fans, pumps, radiators, and heat exchangers
- Acoustic models for predicting flow-induced noise.

5.2 Guidelines for selecting Appropriate Model:

The most important step in solving any multiphase problem is to decide with which of the models our flow best exemplifies. There are guidelines for the same which are as follows:

- In problems where St<<1.0, the flow will be trailed by the particles and one of the three models i.e. discrete phase, mixture, or Eulerian is appropriate. But the mixture model is most appropriate in most cases owing to the factors like expense etc.
- In problems where St >1.0, the flow and the particles travel independently, either the eulerian model or discrete one is deemed appropriate.
- In problems where St~1.0, any of the three models will suffice the problem.
- If dispersed phases will be distributed over a wide domain, the desirable regimes is of mixture. But if it is otherwise i.e. concentrated, Eulerian model is preferred.
- Eulerian model provides more accurate results compared to the Mixture model in cases where interphase drag laws affect the system. The mixture model is of superior choice if the interphase drag laws are unknown.
- The mixture model seems to be working good if a simple solution is required for the problem and less computational effort, moreover fewer equations are solved than the Eulerian model.
- If accuracy is primary than computational effort, wise choice is to model with Eulerian regime.

5.3 Methodology:

5.3.1 Geometry Creation

A two dimensional axisymmetric geometry is created with and due to this symmetry there is reduction in simulation as well as calculation time. This geometry option is used to draw the initial sketches, and then a surface is drawn from the sketch. By double-clicking on the geometry cell, the design modeler window pops up in which the below model is designed.

Geometry is created with:

Length of the pipe - 20m

Thickness of the pipe – 0.5m

Diameter of the pipe – 20cm

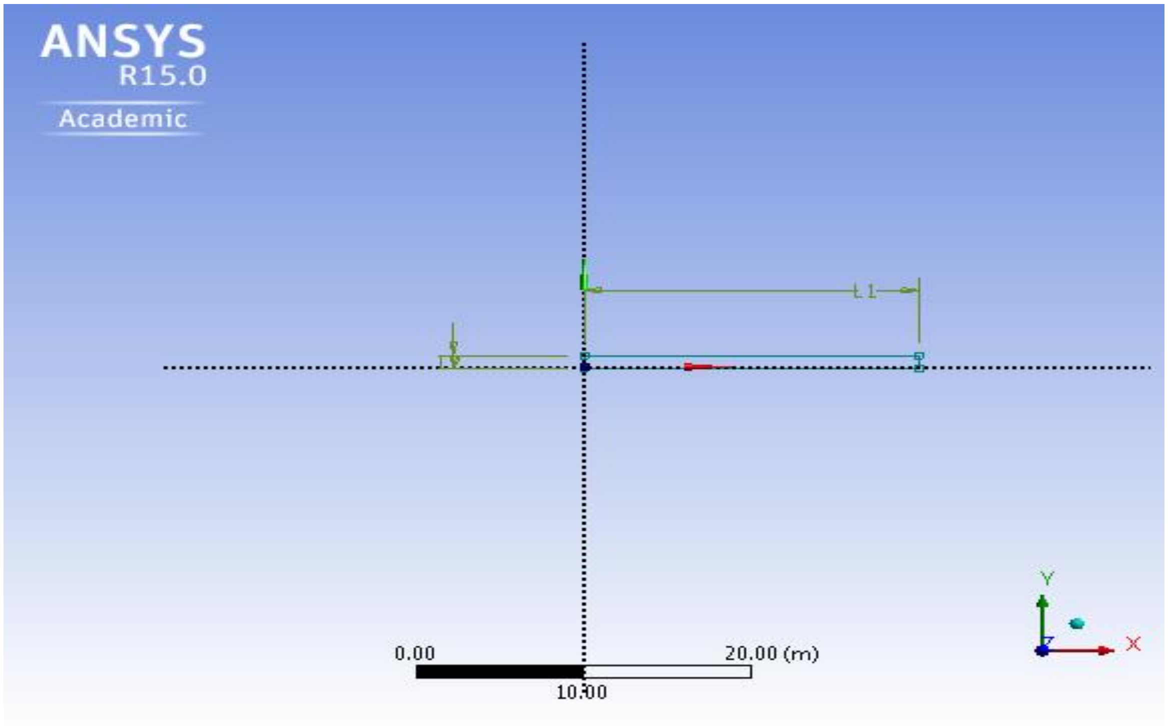


Figure 8: 2-D Geometry of the Pipe

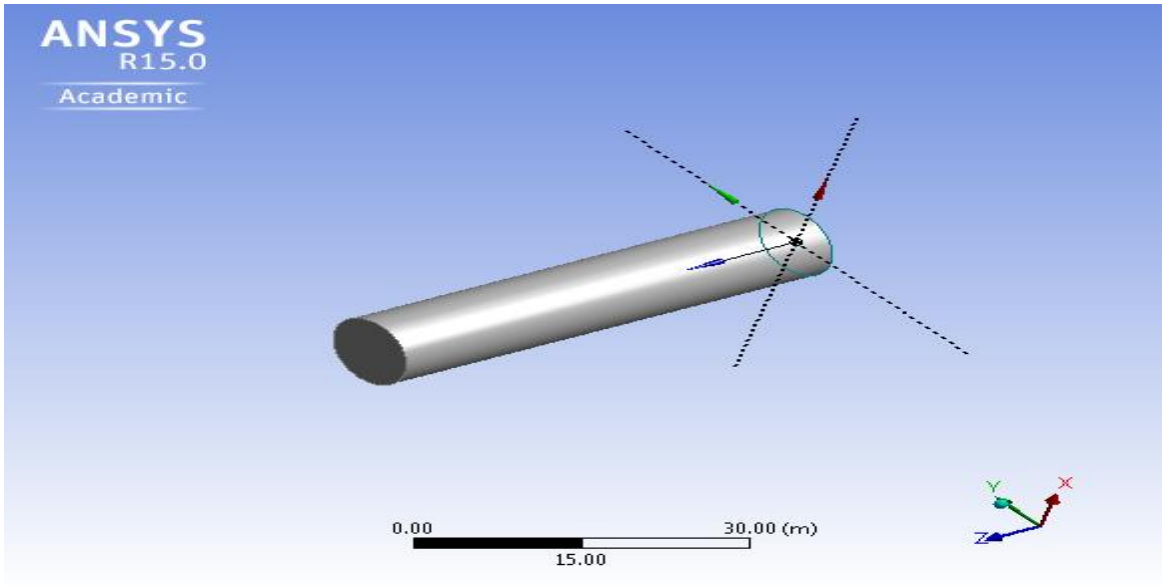


Figure 9: Surface Generation after Sketching

5.3.2 Meshing:

A custom mesh is created with the help of the meshing option. In meshing we divide the face and the edges of the model into appropriate no. of elements by using the face sizing and edge sizing option respectively. The face is divided into 100 elements whereas the edge is divided into 10 elements. With this through named selection option, inlet, outlet, pipe wall as well as centerline are properly marked.

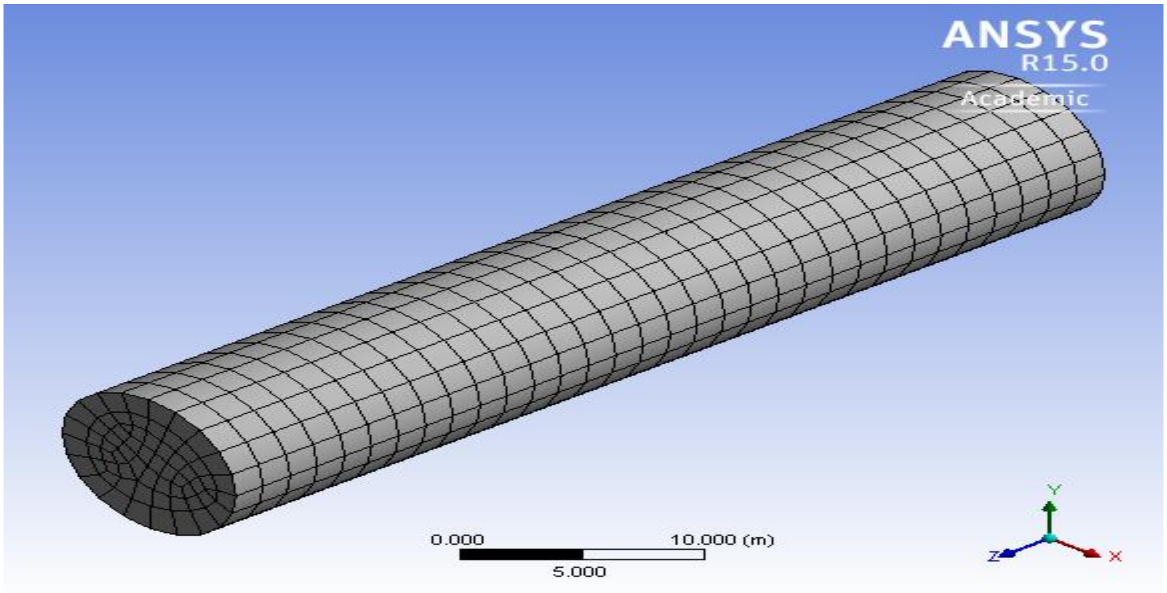
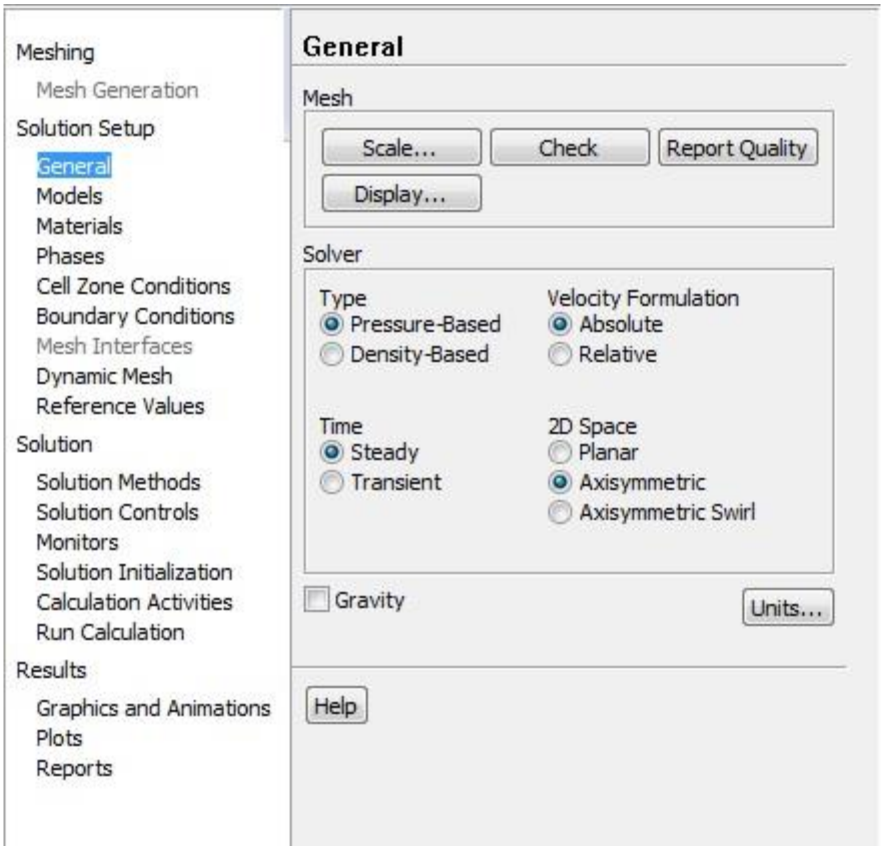


Figure 10: Creating Mesh of The Pipe

5.3.3 Set up and Solution:

The solver is of pressure based solver with axisymmetric 2d space option. Eulerian multiphase model with laminar flow is chose over other because of the concentration of the slurry flow which is higher. Then we provided the material properties and adding the properties of pond ash in the solid section. Then we provide the boundary conditions which are well mentioned in the ANNEXURE-1. The pressures as well as velocities inside the pipe are measured with 70% of pond ash concentration. Granular diameter of the pond ash is taken as 75x10 $^{-6}$ m with slurry velocities of 3.5m/s.



General

Solver

Type
● Pressure-Based
○ Density-Based

Velocity Formulation
● Absolute
○ Relative

Time
● Steady
○ Transient

2D Space
○ Planar
● Axisymmetric
○ Axisymmetric Swirl

☐ Gravity

Figure 11: Solver Set-Up

5.4 ITASCA FLAC:

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 behavior 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 behavior 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).

Features:

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.

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:

- 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.
- 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.
- 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.
- 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.
- FLAC is a robust programming model. It can handle any constitutive model. It does not include any adjustment in the solution algorithm.

5.5 Methodology

The numerical modeling includes mining of a coal seam which is simulated on the geo-mining conditions of KTK-5 mine. The depillaring process is shown in different stages after it is developed in bord and pillar method. The excavations in the seams were carried out to their full thickness.

Width of the pillars - 30m
Width of the development gallery - 4.2m
Width of split gallery - 5m
Width of ribs - 2.5m
Height of galleries - 3m
Depth of Working - 210m

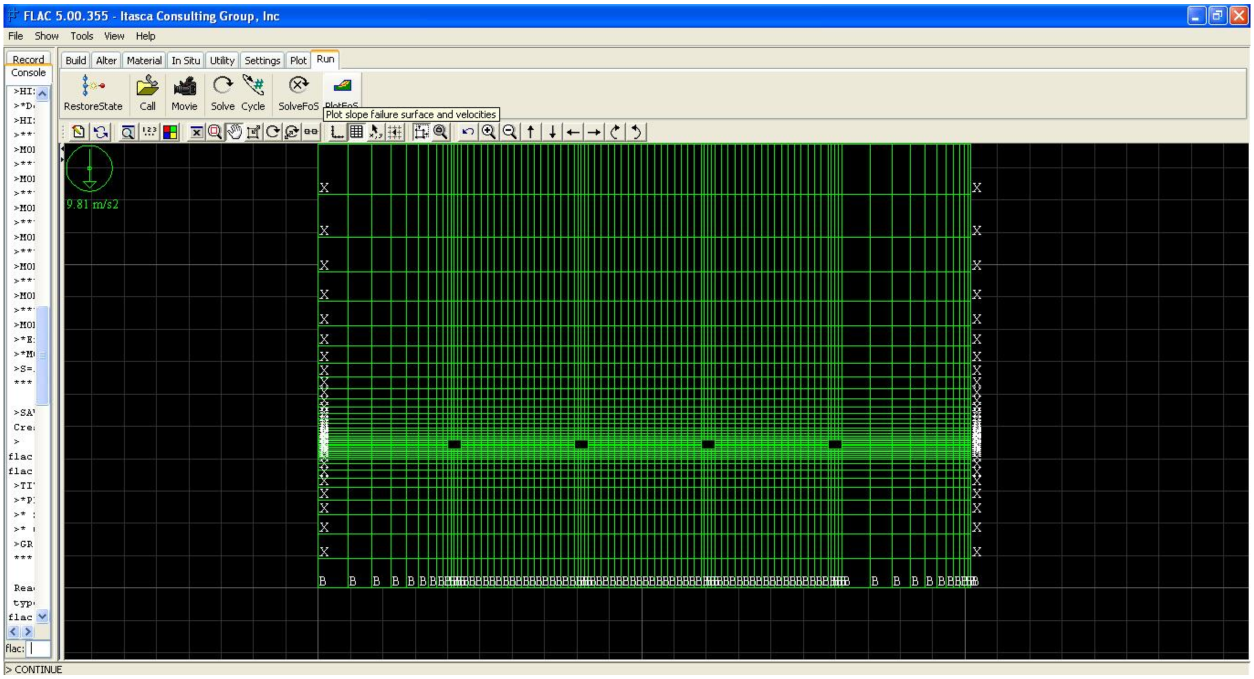


Figure 12: Grid Elements of the Model With Development of Four Gallery Openings In The Seam

The pillar size according to this model which is extrapolated from the mine data of KTK-5 is 30m. After the development of galleries and the pillar generated in the first stage of modeling the pillars were given splits of 5m and the stress distribution around the openings were studied. In the further stages the seam was extracted up to a height of 3m. Ribs were left which was judiciously robbed during final extraction of seam. Numerical modeling was done in order to analyze the stresses upon the area i.e. stooks, ribs etc. where extraction has been done and moreover the roof deformation or displacement was also analyzed.

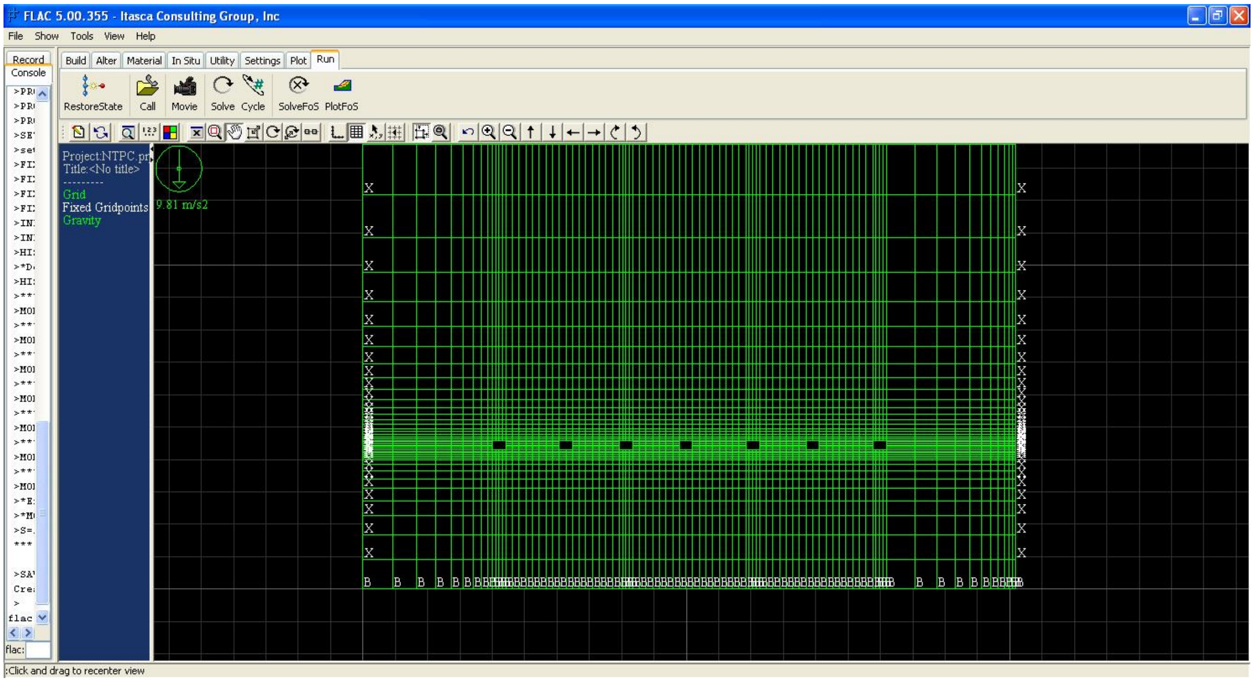


Figure 13: Grid Elements of The Model With 3 Pillars After Splitting of Galleries

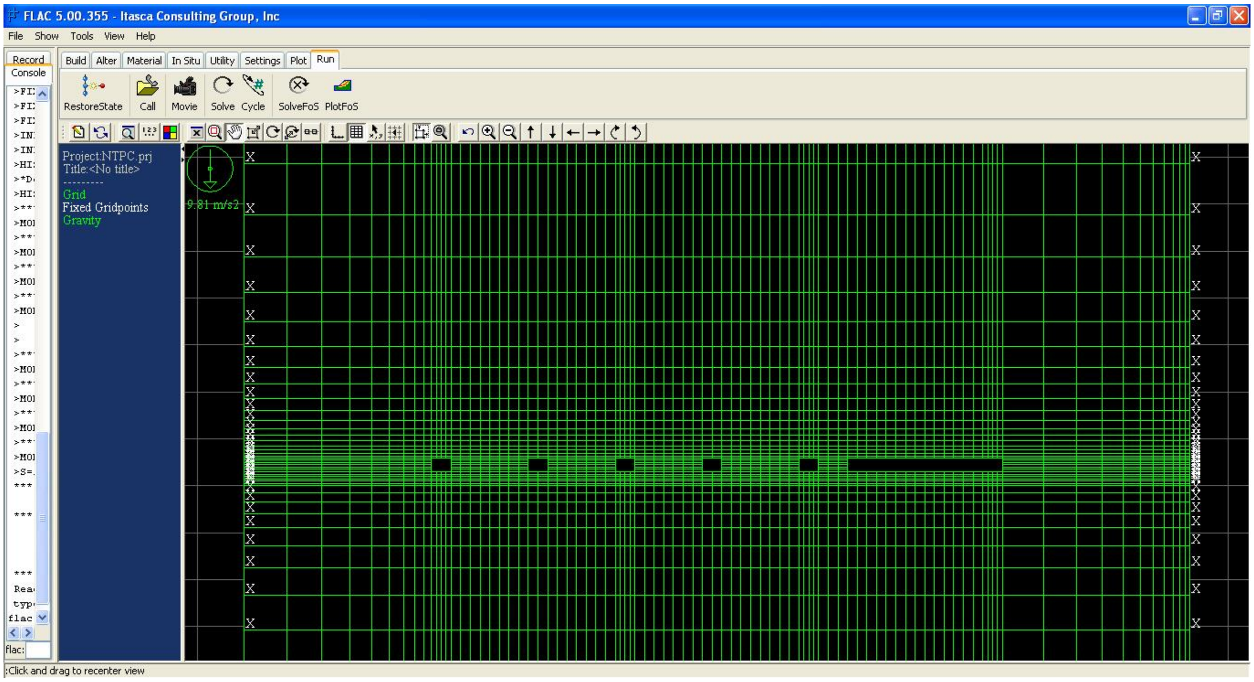
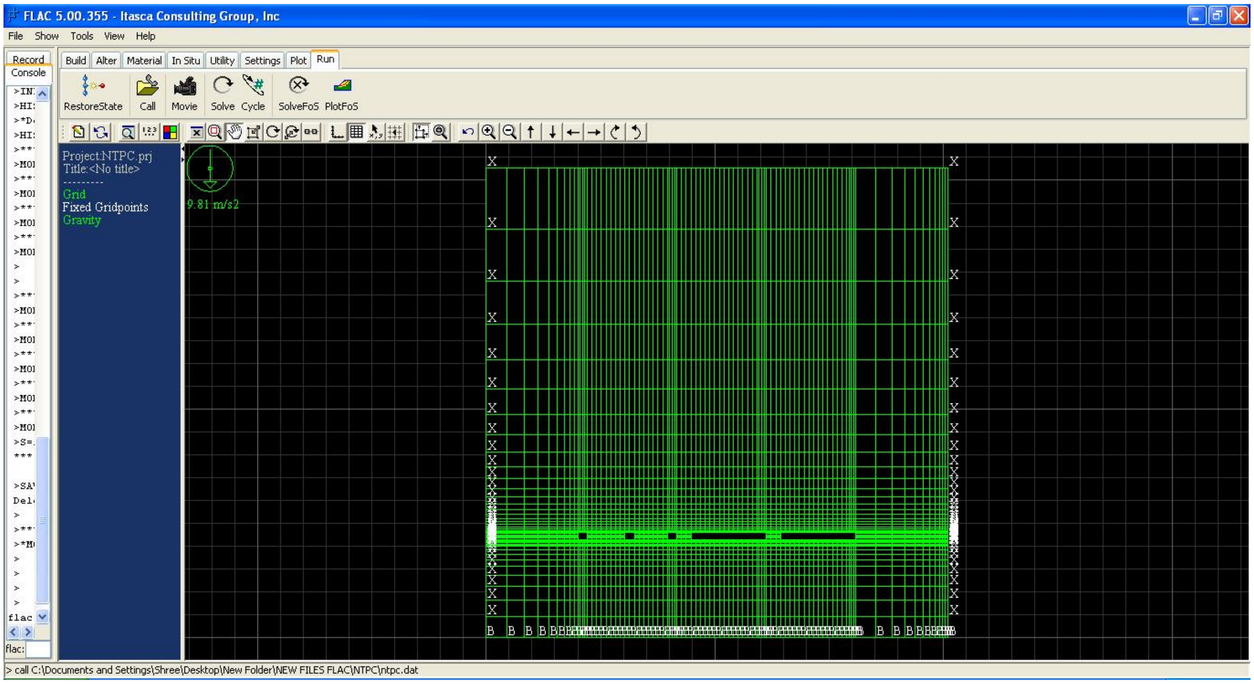
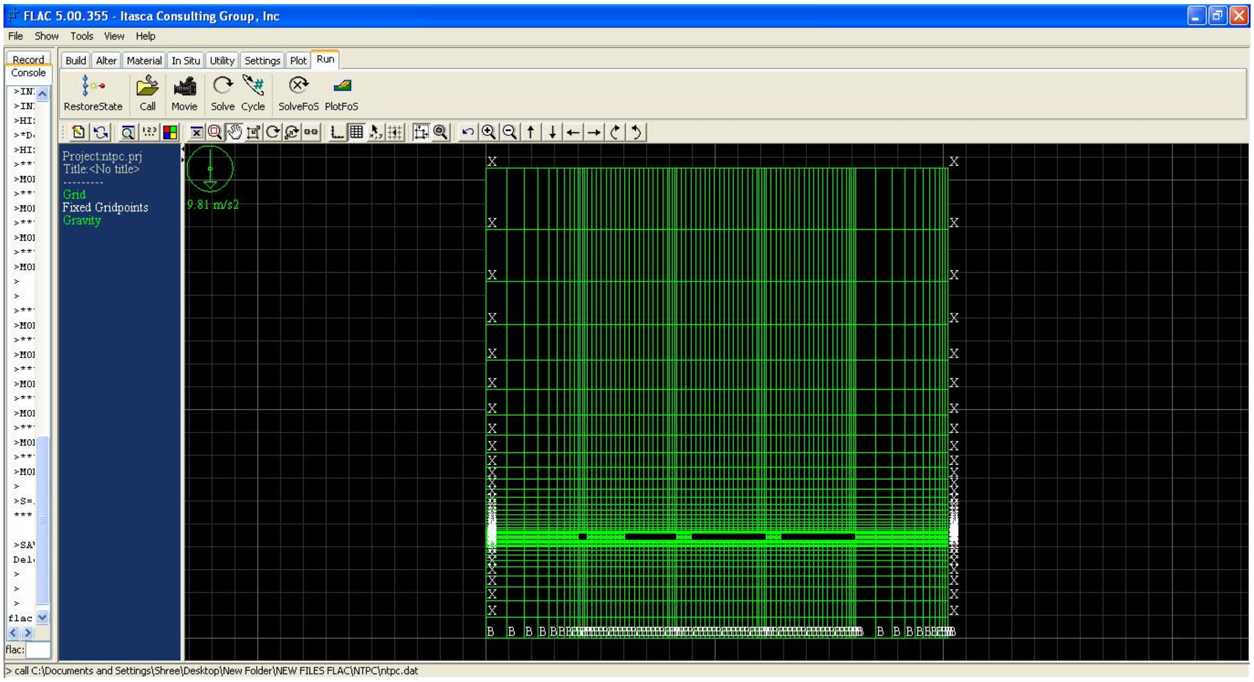


Figure 14: Grid Elements of The Model With 3 Pillars After Extraction of One Pillar



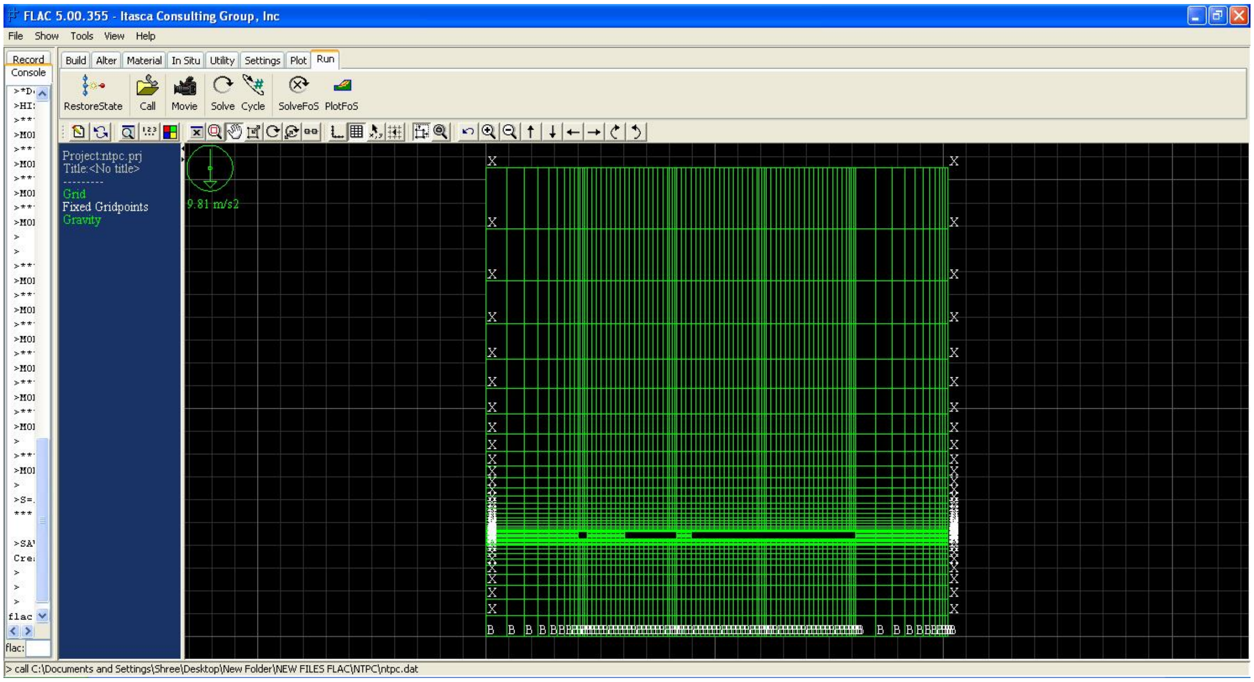
```
> call C:\Documents and Settings\Shree\Desktop\New Folder\NEW FILES FLAC\NTPC\ntpc.dat
```

Figure 15: Grid Elements of The Model With Three Pillars After Extraction of Two Pillars



```
> call C:\Documents and Settings\Shree\Desktop\New Folder\NEW FILES FLAC\NTPC\ntpc.dat
```

Figure 16: Grid Elements of The Model With Three Pillars After Extraction of Two And Half Pillars With Two Ribs And One Stook



Project:ntpc.prj
Title:<No title>

```
> call C:\Documents and Settings\Shree\Desktop\New Folder\NEW FILES FLAC\NTPC\ntpc.dat
```

Figure 17: Grid Elements of The Model With Three Pillars After Extraction of Two And Half Pillars With One Rib And One Stook

5.5.1 Sequence Of Simulation Of Pillars In Development Stage And Excavation Stage Was:

Step 1	development stage – pillars and galleries of appropriate size were developed in the seam.
Step 2	providing three splits in four pillars.
Step 3	the row pillars are extracted with a single rib left inside the goaf
Step 4	two row pillars are extracted from the seam with two ribs left inside the goaf.
Step 5	two and half row pillars extracted with two ribs left
Step 6	two and half row pillars were extracted with one rib left inside the goaf in the seam.

5.5.2 Assumption In The Model

The elements in the model that are considered are small. The elements in the ribs are of size 0.5m in the ribs and 1m in the pillar. Each of them at max represents $2m^2$. The mesh elements dimension increases gradually and geometrically from inner model to outer boundary. This in turn reduces the computational and simulation time. There is approximate boundary features and pattern of grid for varying cover of depth. The extraction model is developed from the developmental model as described above. The condition that the model undergoes is plain strain and Mohr coulomb criterion. The depth covers of the floor material is of sandstone element. Properties of coal and sandstone upon which the entire development is done and that of pond ash fly ash and sand is used are as follows:-

Table 10: Properties of The Filling Materials

Properties	Coal	Sandstone	Pond ash	Fly ash	Sand
Young's modulus	2GPa	5GPa	1.66MPa	2.1MPa	3.85MPa
Poisson's ratio	0.25	0.25	0.33	0.28	0.46
Cohesion	1.85MPa	6.75Mpa	40KPa	35.6KPa	39.4KPa
Density	$1480kg/m^3$	$2100kg/m^3$	$1900kg/m^3$	$1750kg/m^3$	$1600kg/m^3$
Tensile strength	1.86MPa	9GPa	0	0	0
Angle of internal friction	30	45	31	34.5	28.45

There is freedom to the top of the model to move in any direction. There is constraint for the edge of the model to move in vertical i.e. y direction. The bottom edge is applied with roller type of boundary conditions i.e. body can move in horizontal direction but not in vertical i.e.. up and down.

Since there was no way that in-situ stress from the mine could be practically found out, the stress was calculated by the following formulae.

Vertical Stress = $\rho \times H$

Horizontal Stress = $3.75 + 0.015\,H$

Where

ρ = specific weight of the overlying rock mass

H= depth cover

There is effect of graduated stress due to gravity. The in-situ stresses are generated for run of the model and before simulation of the mine with openings or galleries. The displacements are again reset to zero. Then the simulation is run by developing the mine openings, then extraction and at last stowing. In stowing the area which is to be stowed instead of setting it to null and then adding up the material, the area has that has to be stowed is provided with the material properties of stowing material. Then the model was run to find out the various parameters including factor of safety which is calculated after the end of the extraction of two and half pillars with each type of fill uses and when not used. The final stress distributions as well as the displacement of the roof are plotted.

Chapter – 6

RESULTS and ANALYSIS

- STRESS GENERATED OVER PILLARS (AFTER DEVELOPMENT), STOOKS and RIBS (AFTER EXTRACTION OF TWO AND HALF PILLARS)
- STRESS GENERATED OVER STOOKS and RIBS (AFTER EXTRACTION OF TWO AND HALF PILLARS AND STOWING) WITH POND ASH, FLY ASH AND SAND
- DEFORMATION OF ROOF AFTER EXTRACTION WITH FILL AND WITHOUT FILL
- ANALYSIS OF THE RESULTS OBTAINED THROUGH GRAPHS
- PRESSURE, VELOCITY AND VOLUME FRACTION ANALYSIS OF THE POND ASH SLURRY TRANSPORTATION IN PIPES

6.1 ANSYS RESULTS:

The velocity of the water phase at different positions is measured at interior surface. The contours of the same are plotted. Similarly the velocity of the pond ash is also estimated at different positions of the pipe.

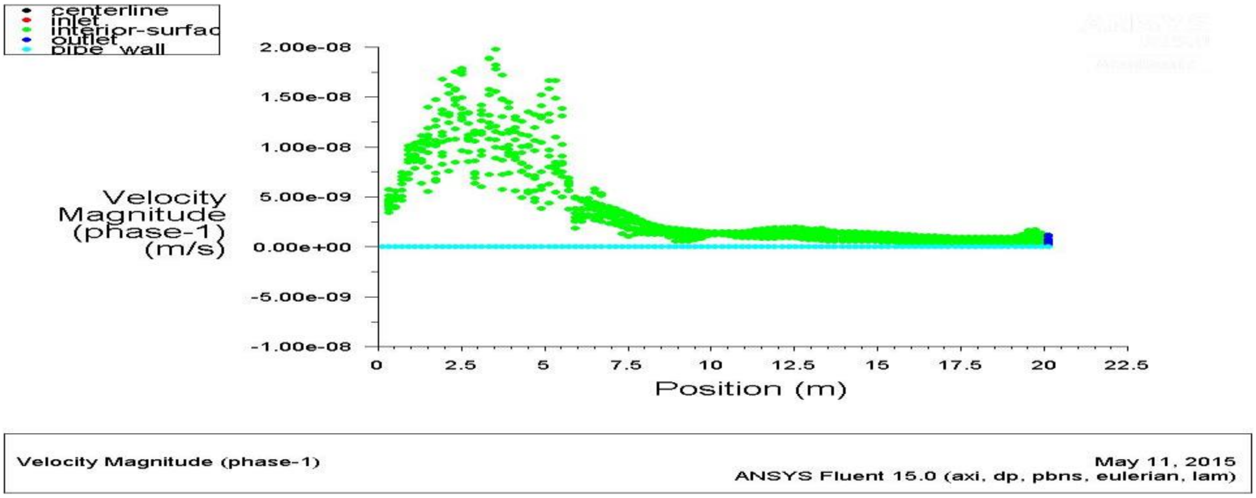


Figure 18: Velocity X-Y Plot of Phase 1 (Water-Liquid)

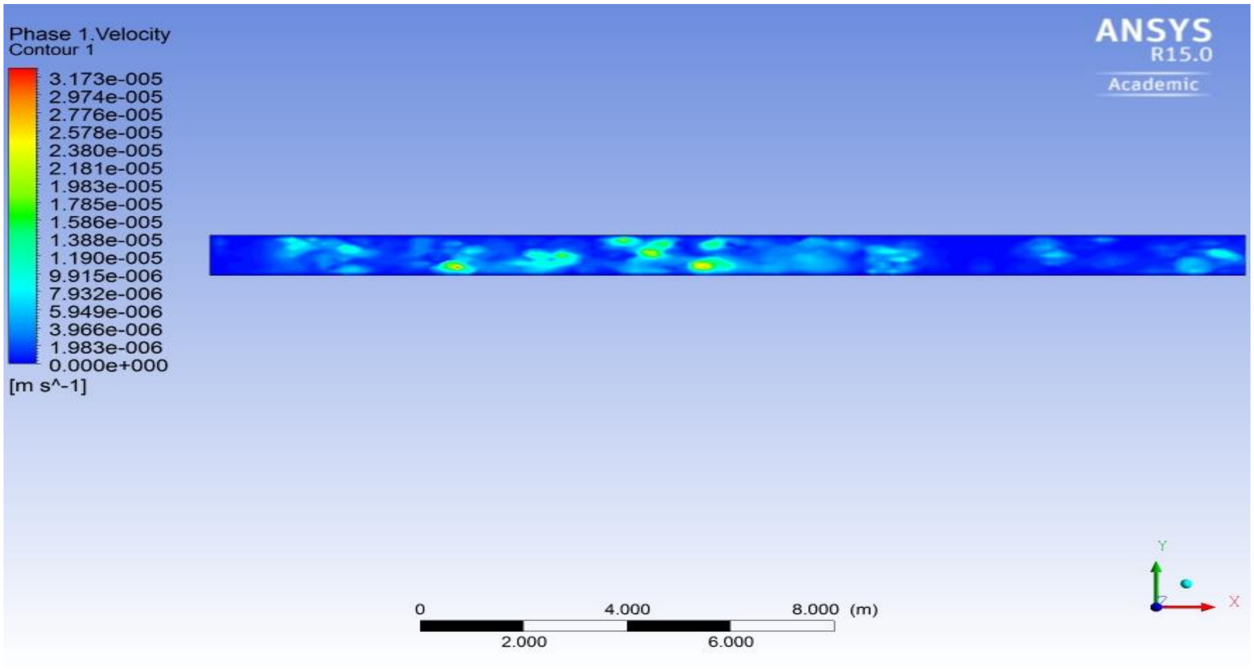


Figure 19: Velocity Contour of Phase 1 (Water-Liquid)

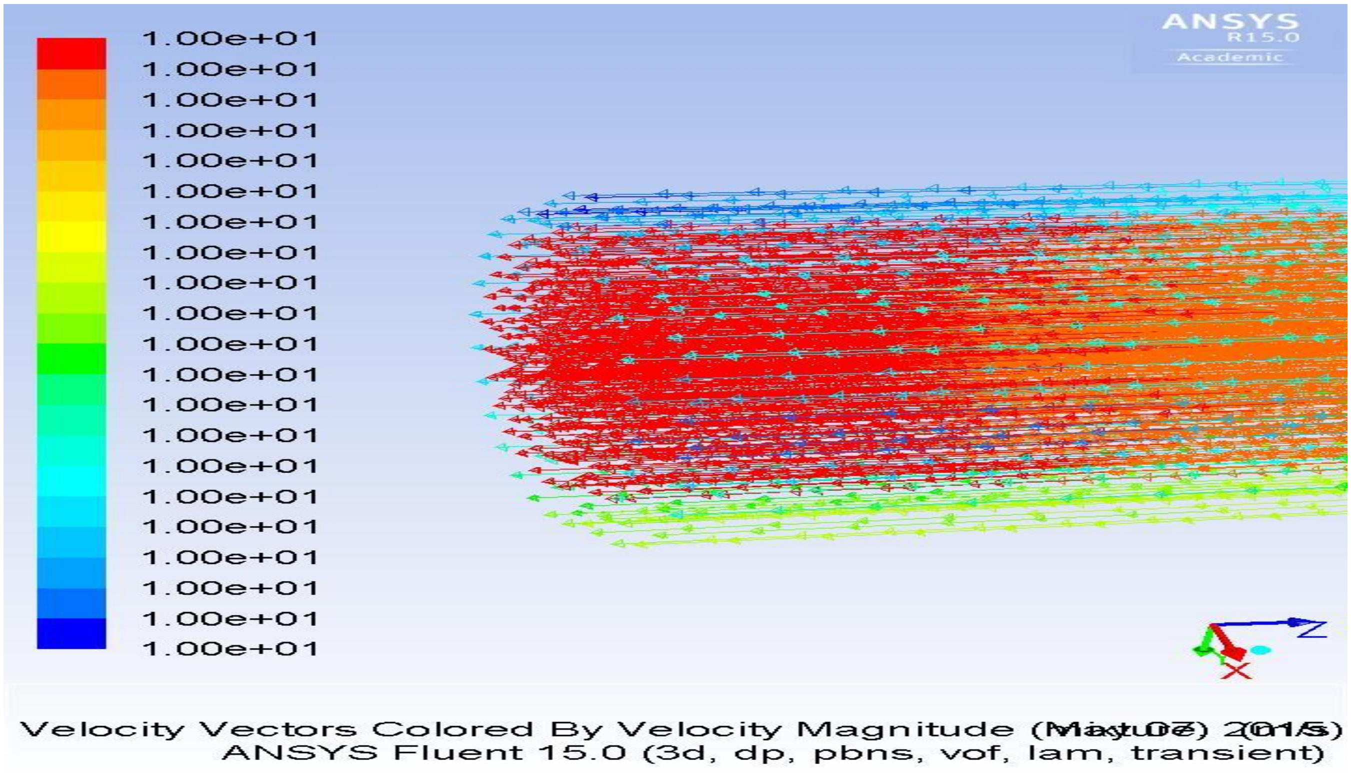


Figure 20: Velocity Vectors at Inlet of Phase 1

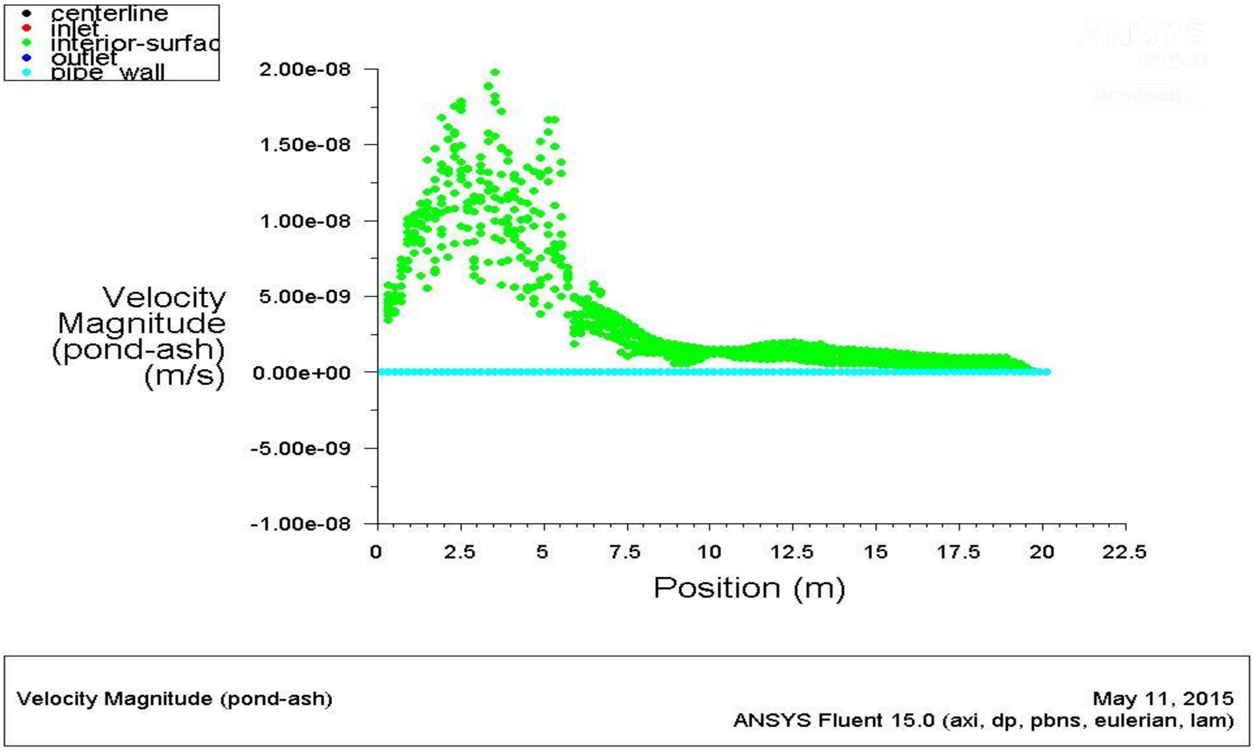


Figure 21: Velocity X-Y Plot of Phase 2 (Pond-Ash)

Static pressure of the mixture is estimated at different locations of the pipe i.e. interior surface as well as pipe wall. The contour of the pressure developed in the pipe is also plotted.

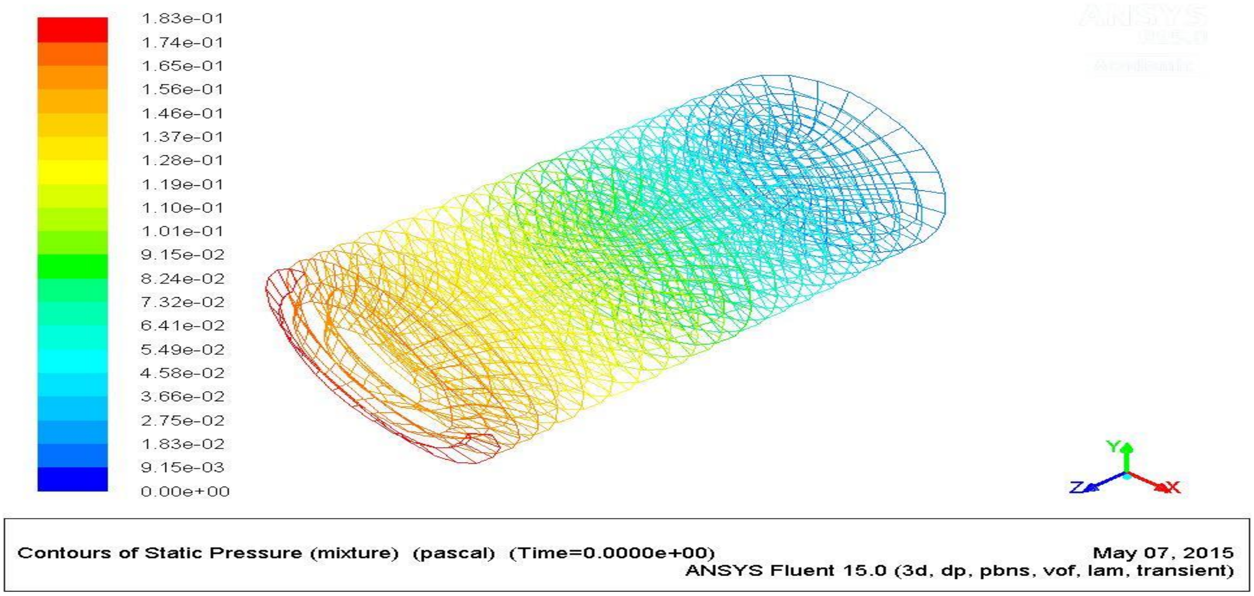


Figure 22: Contours of Static Pressure During Flow of Mixture

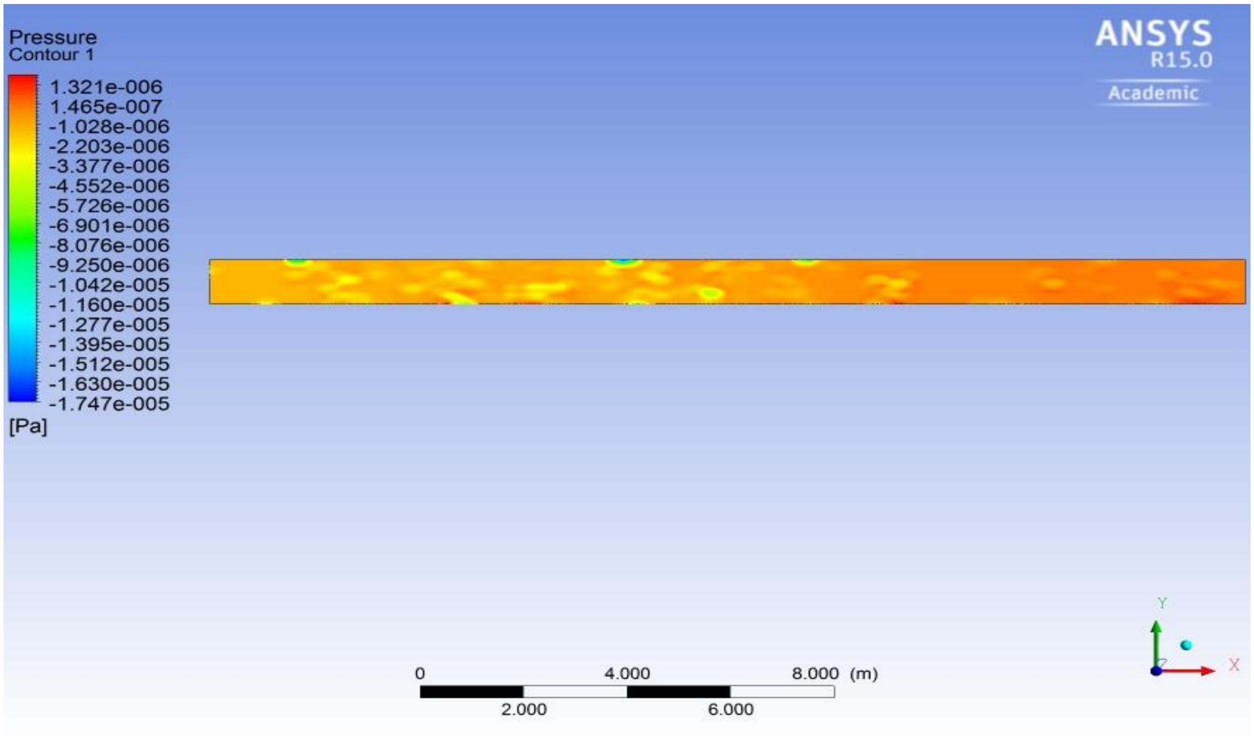


Figure 23: Contours of Total Pressure in The Pipe During Flow of Mixture

Volume fraction in a mixture corresponds to the ratio of the composition of its components volume to the total volume of the mixture. From the contour of the volume fraction plotted it can be seen that volume fraction of pond ash maintains uniform concentration in the beginning of the flow and whereas more of the same can be seen at the bottom end of the pipe. Reasons for such being the viscosity and density which remained high in the slurry as well as sedimentation observed along the pipe length.

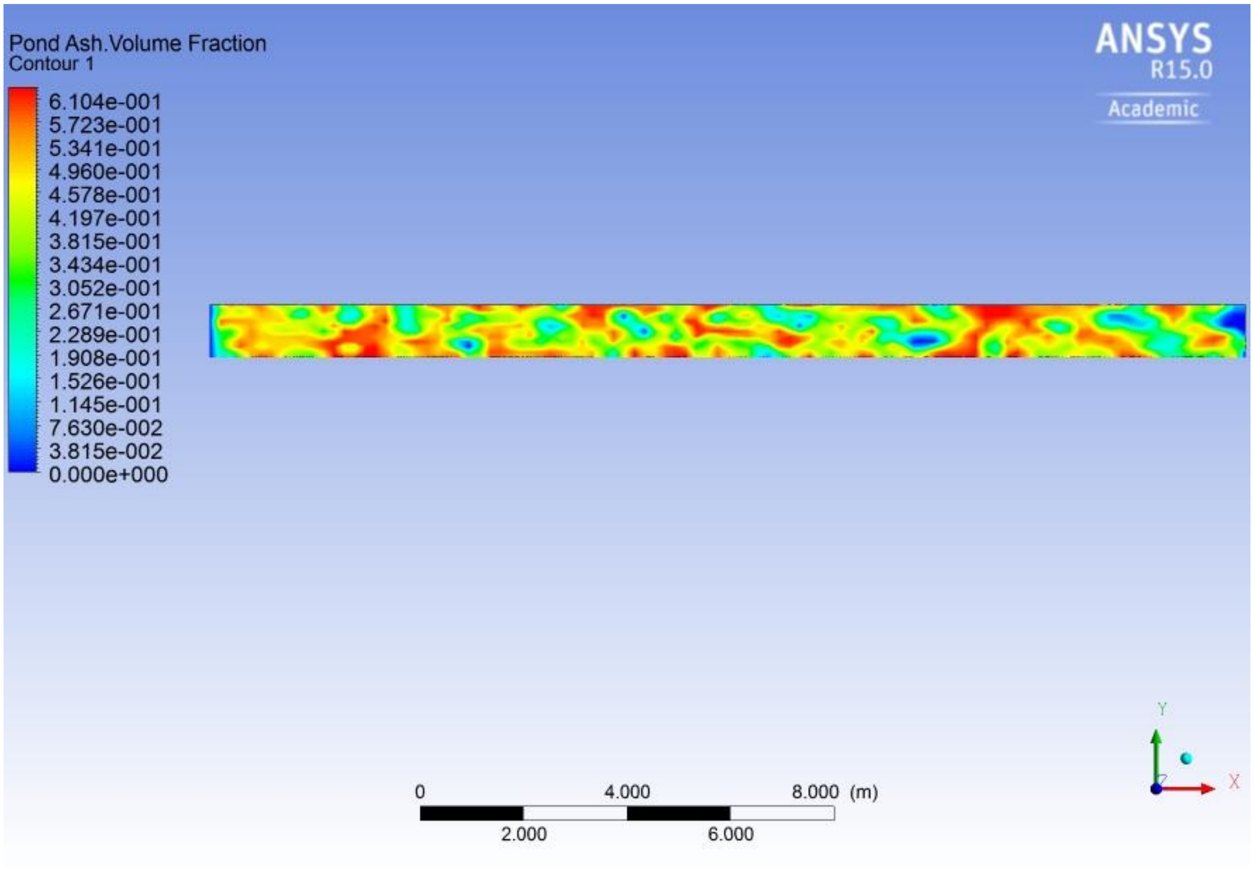


Figure 24: Volume Fraction of Pond-Ash in Total Volume by Weight

6.2 Flac Results:

1. Stress distribution around the openings and displacement of the roof after stage wise extraction of 1st pillar, two pillars and then two and half pillars with two ribs and at last with two and half pillars with judicious robbing of the ribs.

2. Stress distribution again with the backfilling materials i.e.. with pond ash, fly ash and sand after stage wise extraction of 1st pillar, two pillars and then two and half pillars with two ribs and at last with two and half pillars with judicious robbing of the ribs.

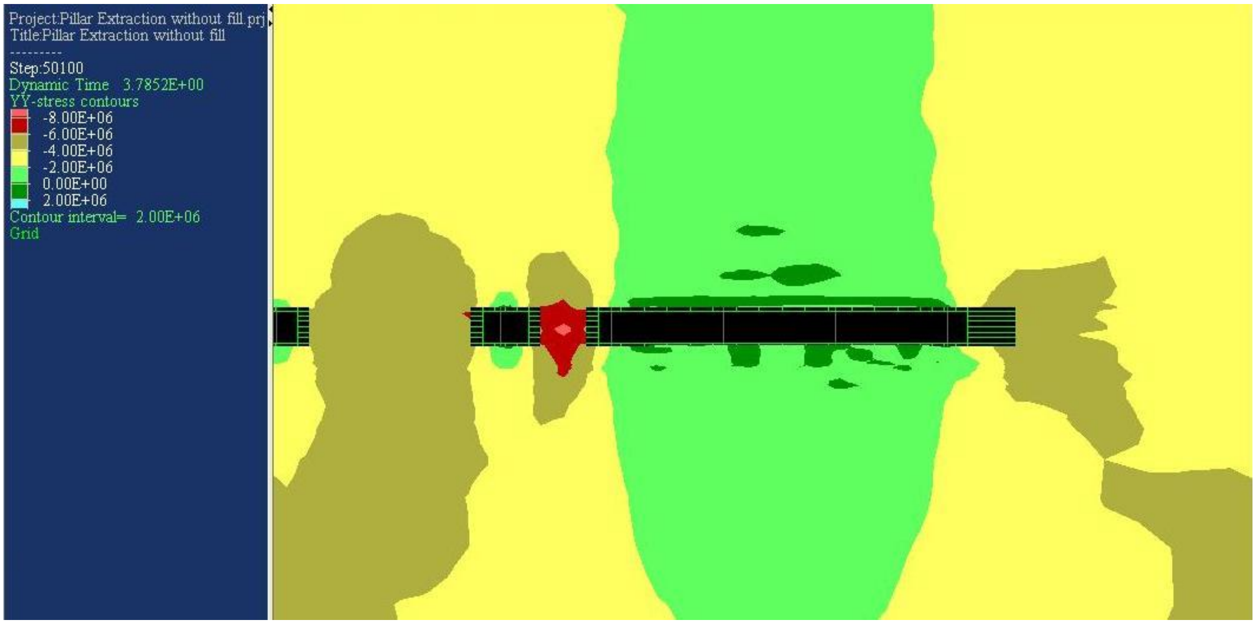


Figure 25: Stress distribution after extraction of 1st pillar

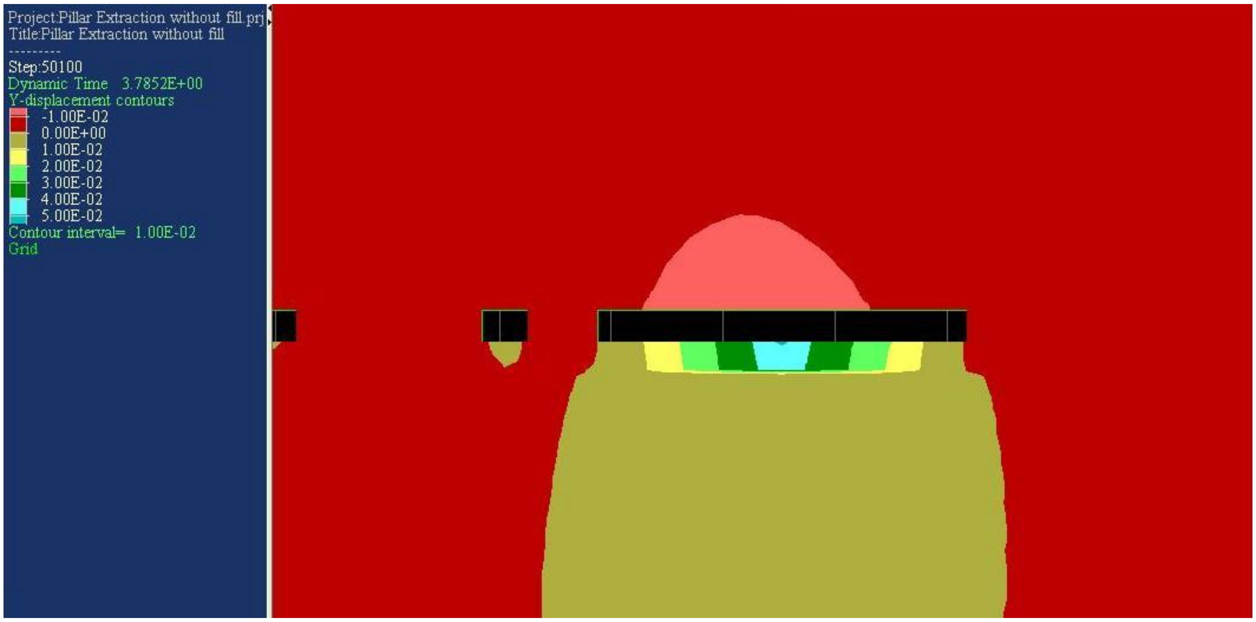


Figure 26: Displacement of the roof after excavation of 1st pillar

Maximum stress was observed on the rib after extraction of 1st pillar which was 8MPa. Vertical displacement of the roof was maxi-mum at the pillar region with 15mm dip at central region.

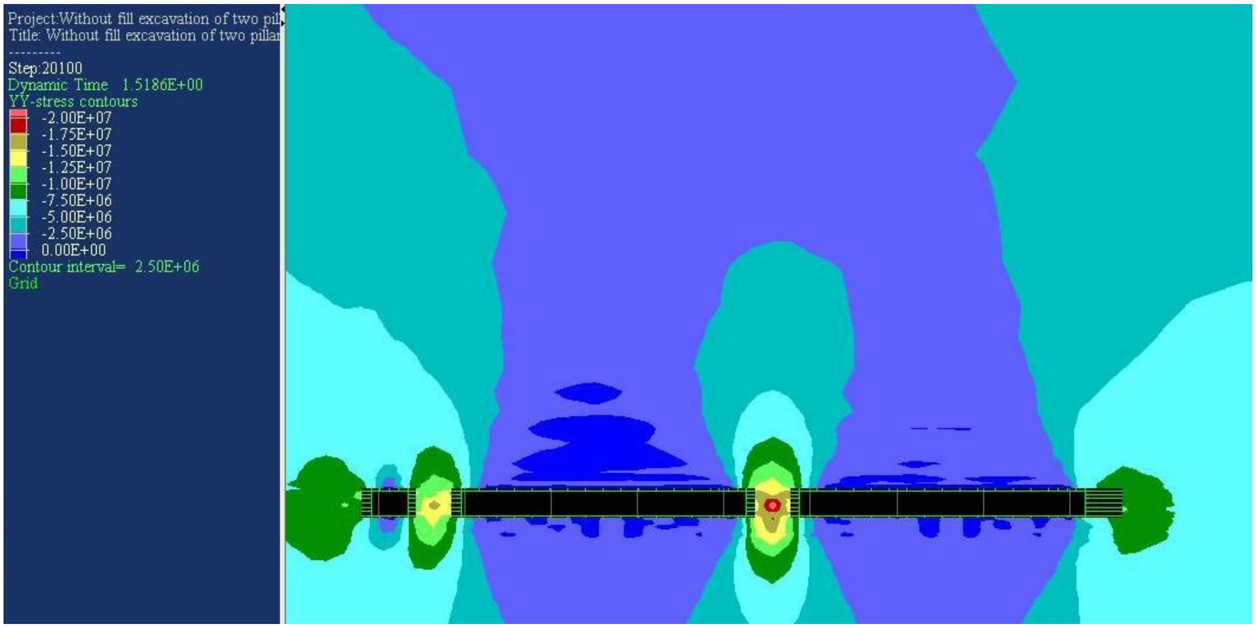


Figure 27: Stress distribution after extraction of 2nd pillar

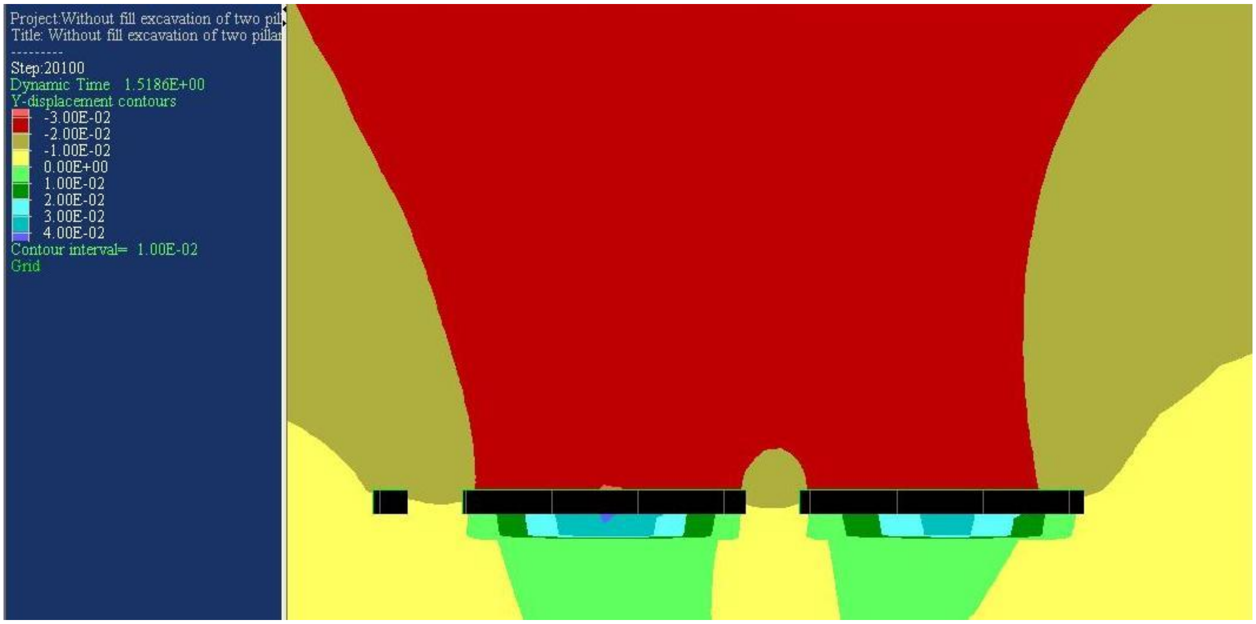


Figure 28: Displacement of the roof after excavation of 2nd pillar

Maximum stress after the excavation of two pillars was found again at rib1 with 10MPa & rib2 with 7.5MPa. The deformation suffered by the excavation was maxi-mum at 1st pillar as well as 2nd pillar with more than 20mm deformation in the range of 20-30mm. Moreover deformation of the ribs was also found to be 20mm.

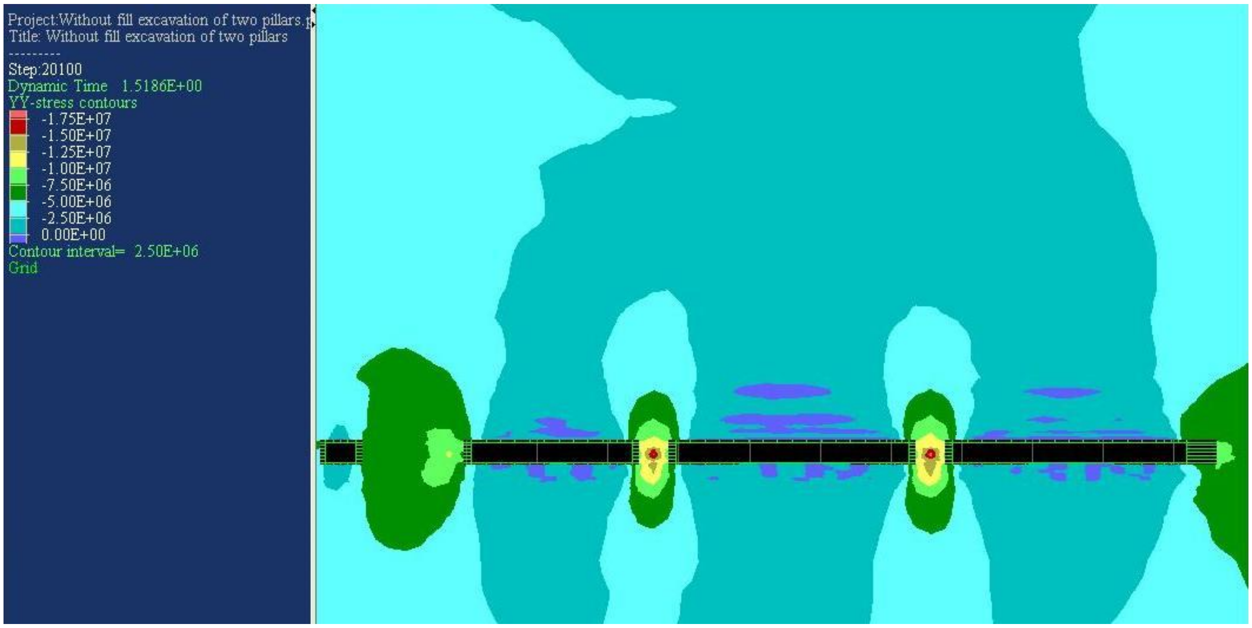


Figure 29: Sress distribution after extraction of two and half pillars

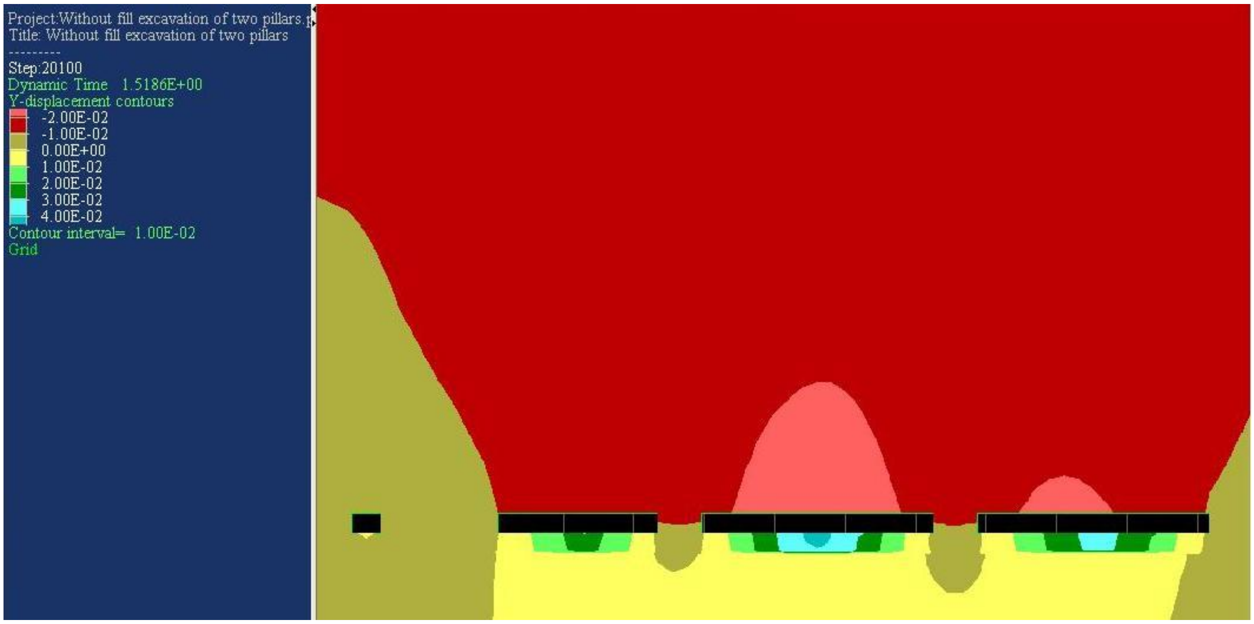


Figure 30: Displacement of the roof after excavation of two and half pillar

Maximum stress on the rib1 as well as rib2 was 20MPa after excavation of two and half pillars. Similarly most displacement of the roof was observed at pillar1, pillar2 and stook1 with 40mm whereas displacement of roof at rib1 and rib2 was found to be 25mm.

Figure 31: Stress distribution after extraction of two and half pillars with one rib

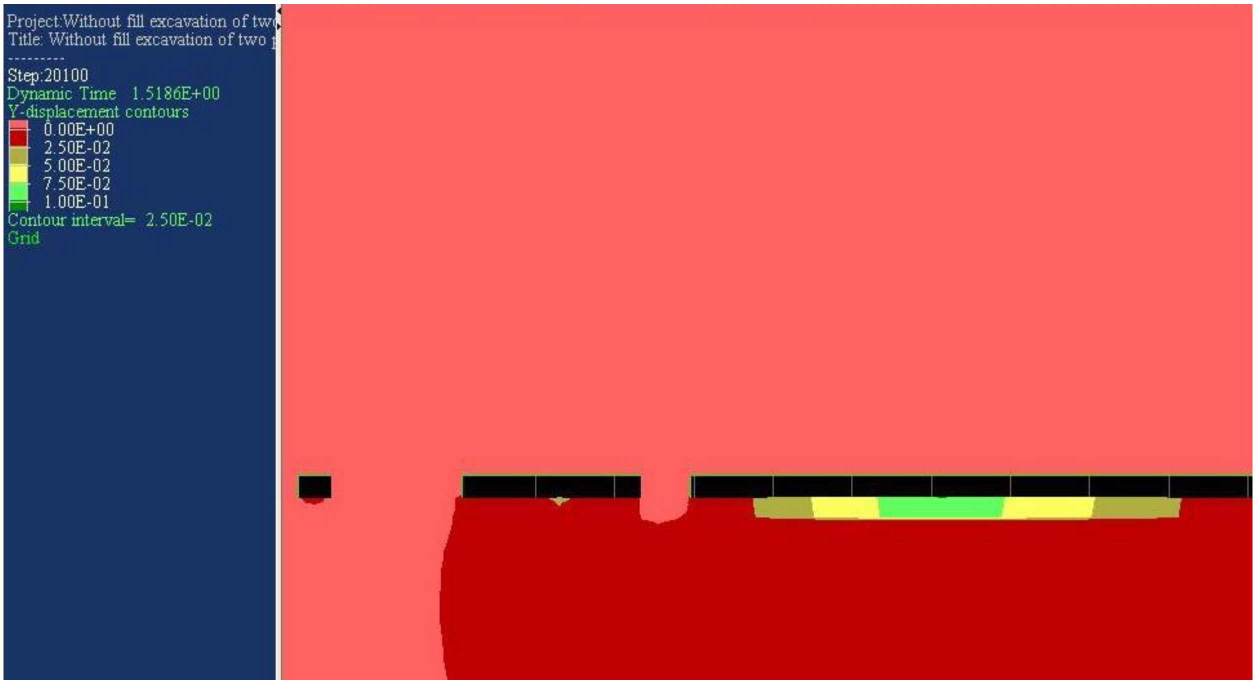


Figure 32: Displacement of the roof after excavation of two and half pillar with one rib left

After extraction of two and half pillars with rib stress was observed to be much higher at stook 1 which was 10MPa whereas in pillar 1 and pillar 2 were 5MPa. Similarly displacement of the roof was observed to be maxi-mum from the previous stages. The deformation was 50mm for pillar 1, pillar 2, pillar 3 whereas 25mm with stook 1.

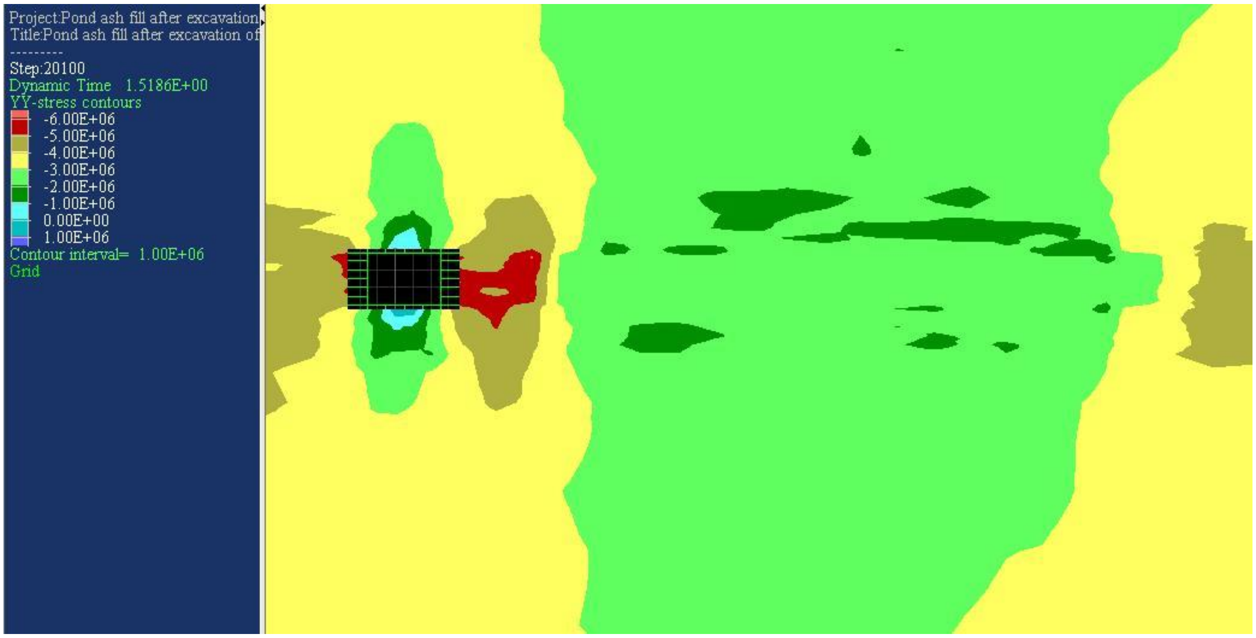


Figure 33: Stress distribution after extraction and backfilling of 1st pillar with pond ash

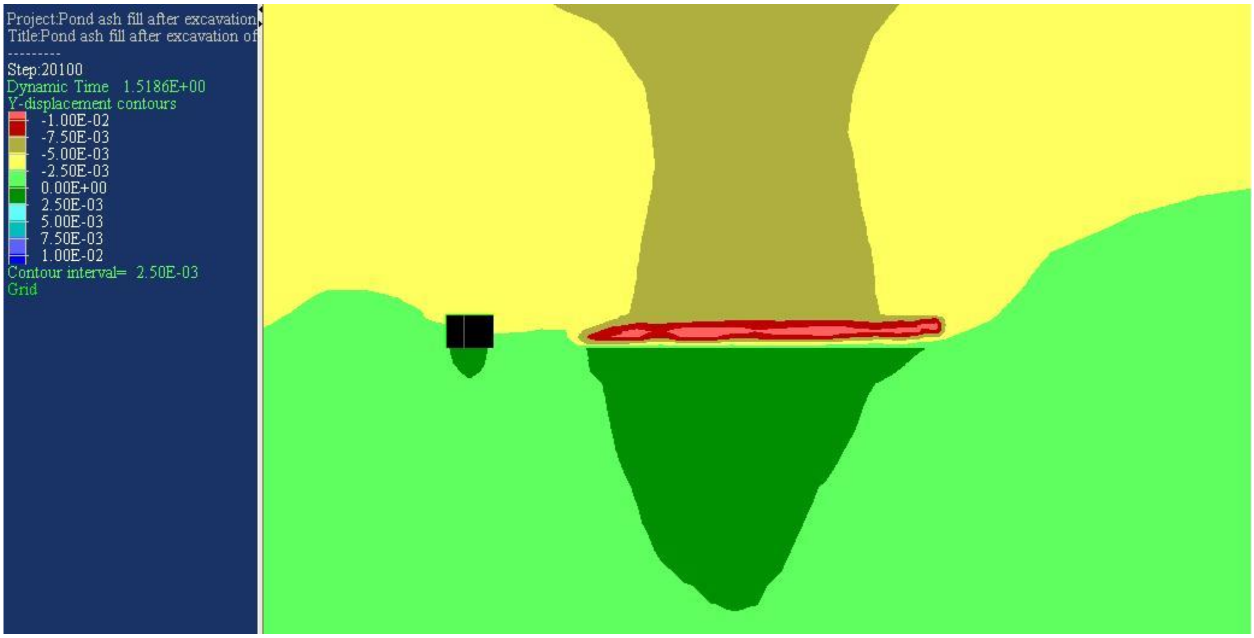


Figure 34: Displacement of the roof after excavation and backfilling of 1st pillar with pond ash

After stowing of the pillar 1 with pond ash the stress was observed to be around 6MPa max.at rib1 and stook where without fill it was 8MPa. Then with the displacement of the roof the magnitude was 7.5mm with pillar1 at most and traces of 5mm deformation was all around.

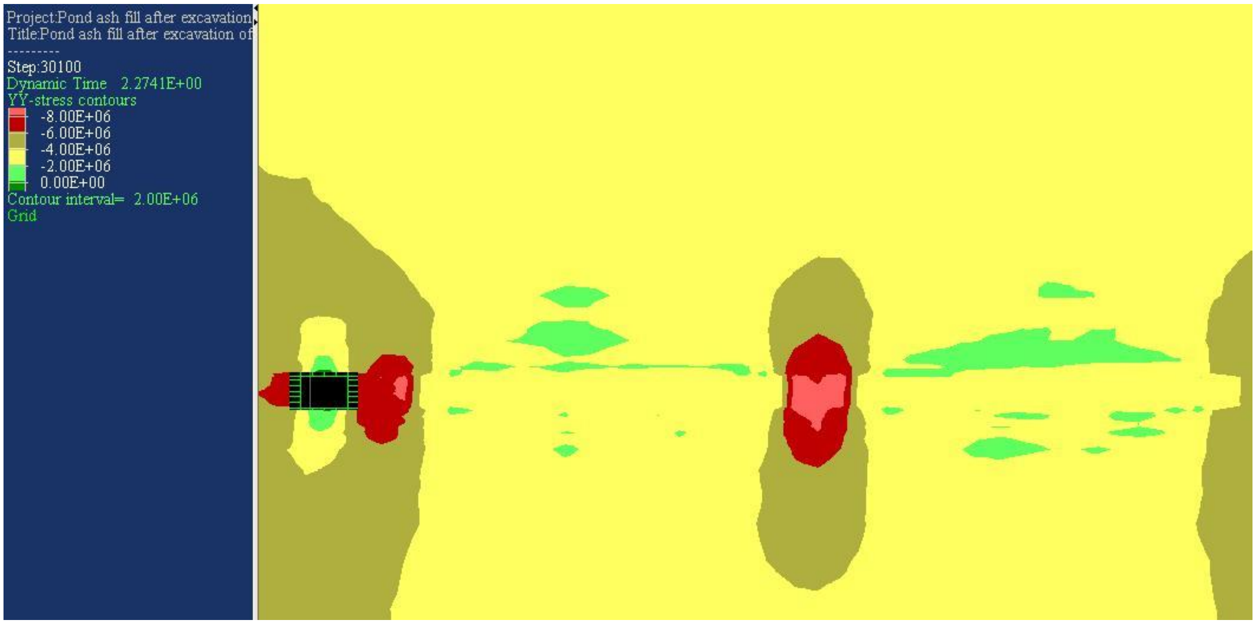


Figure 35: Stress distribution after extraction and backfilling of two pillars with pond ash

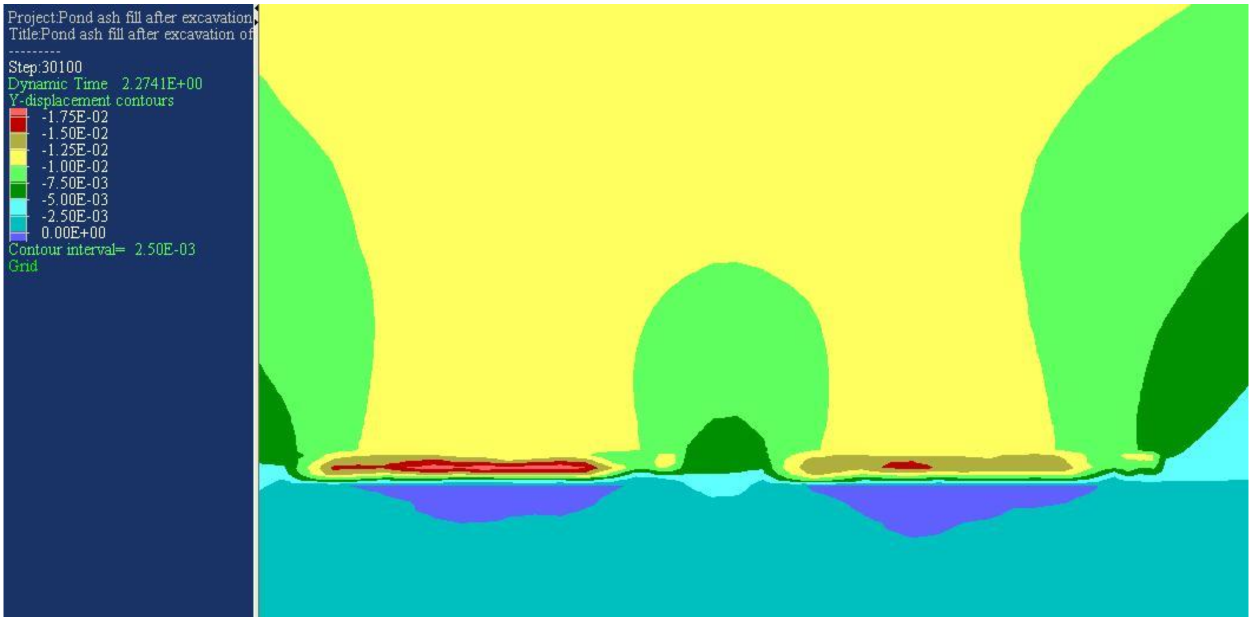


Figure 36: Displacement of the roof after excavation and backfilling of two pillars with pond ash

Maximum stress suffered by the system after excavation and stowing of two pillars were 8Mpa with rib 1, 7Mpa with rib 2, 6MPa with stook. Moreover the shrinkage of the pond ash filled area was uniform with a measure of 12mm around pillar 1, rib 1, pillar 2 and rib 2. Some places were measured with deformation of more than 15mm.

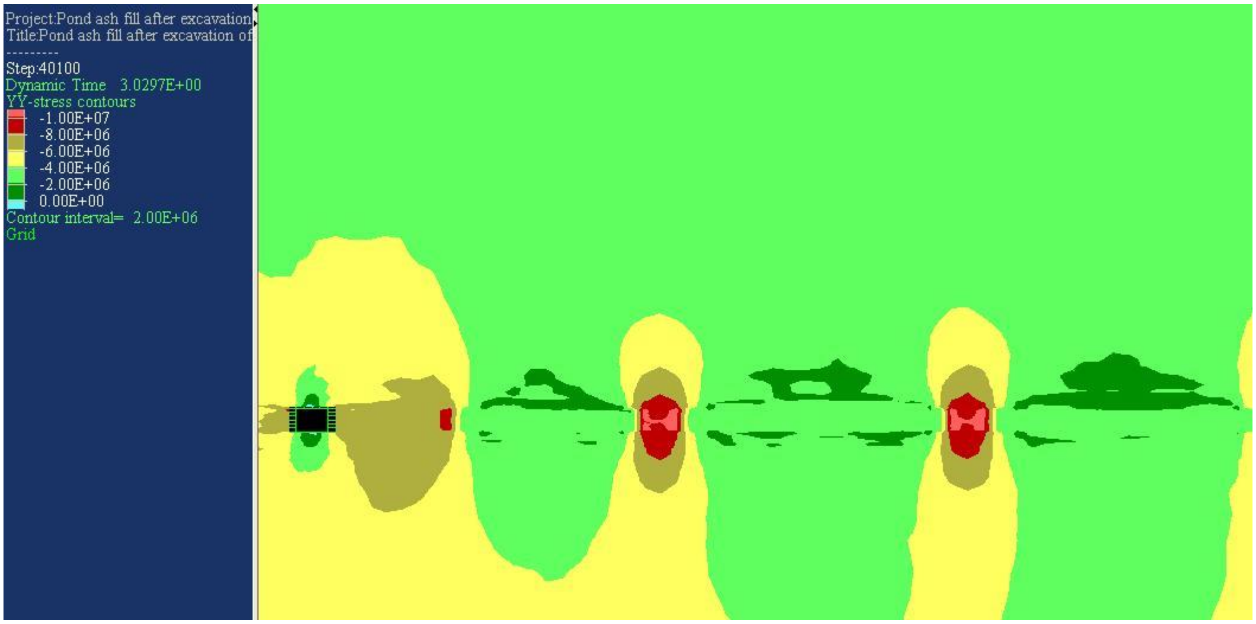


Figure 37: Stress distribution after extraction and backfilling of two and half pillar with one rib with pond ash

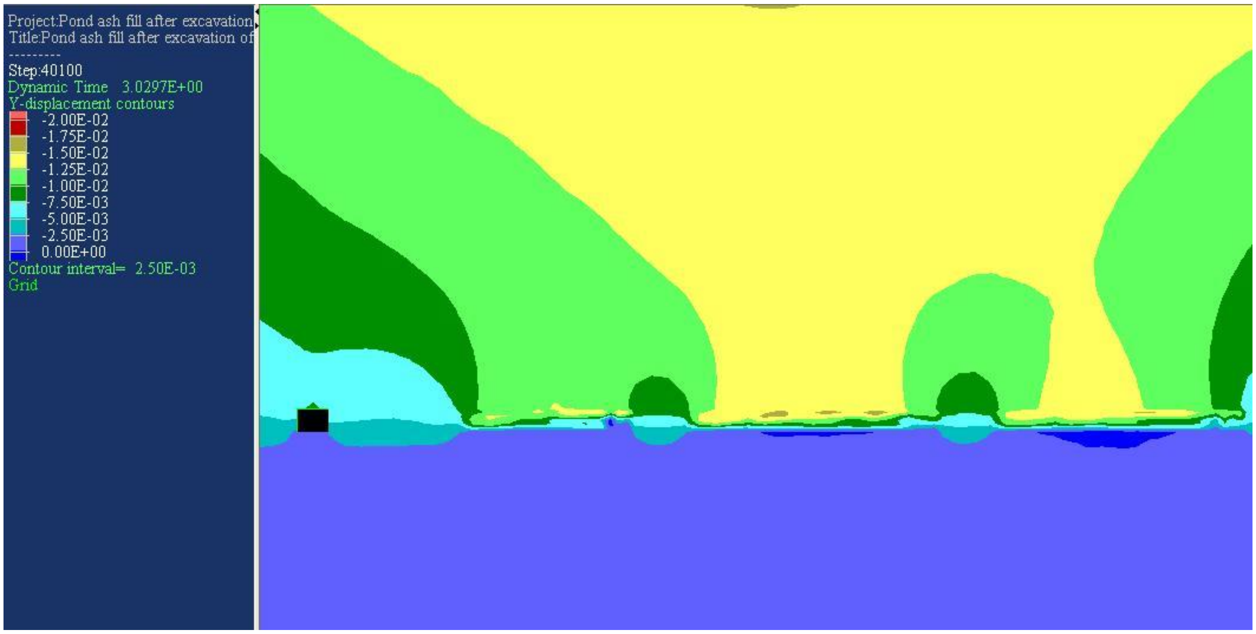


Figure 38: Displacement of the roof after excavation and backfilling of two and half pillar and one rib left with pond ash

Stress after excavation of two and half pillars with judicious robbing of pillars is maxi-mum at the ribs showing 8MPa to 10MPa. Displacement of roof after stowing is observed to be of the order 10mm at pillar1 and pillar2. Also there is deformation of 5mm at the stook.

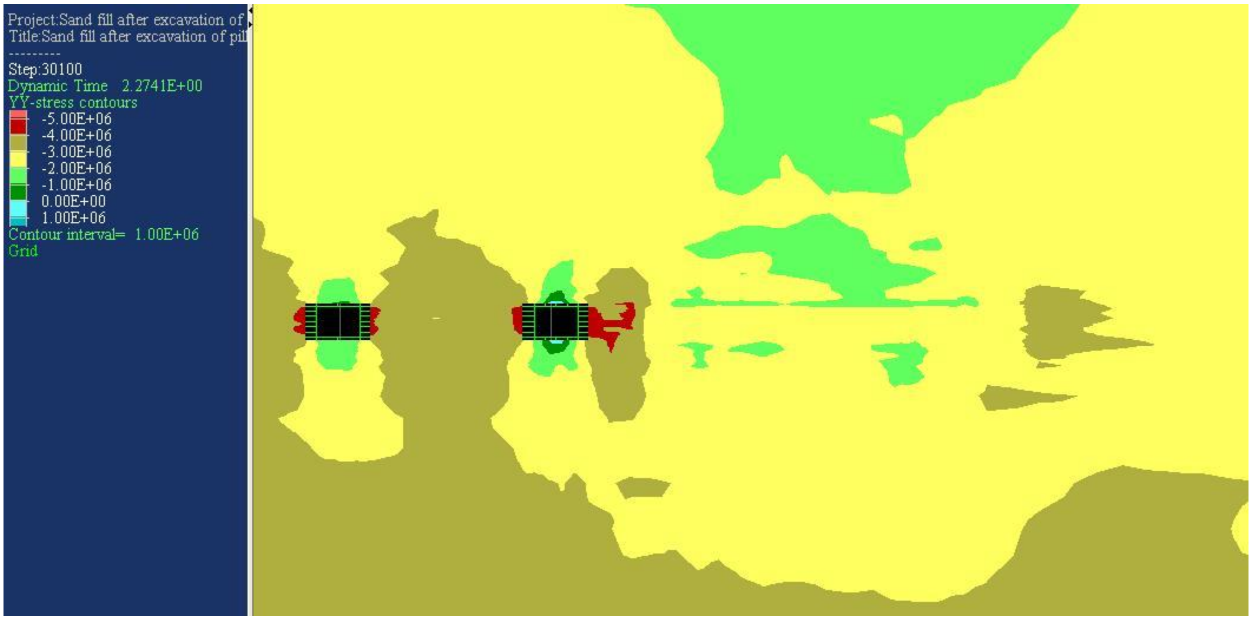


Figure 39: Stress distribution after extraction and backfilling of 1st pillar with fly ash

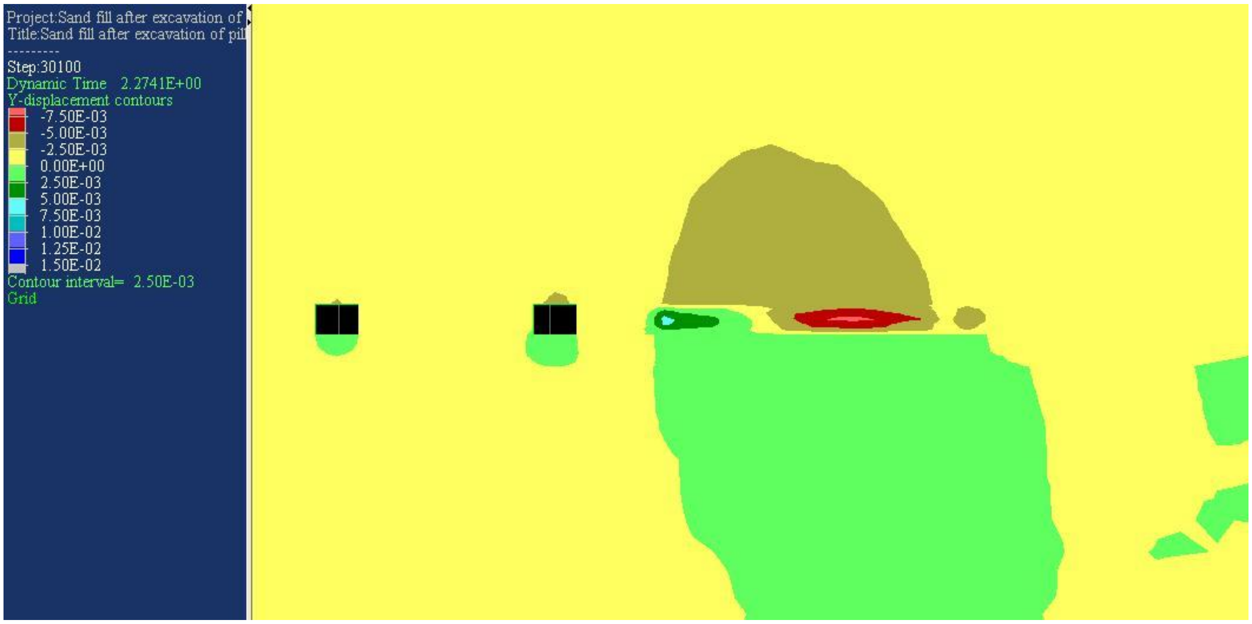


Figure 40: Displacement of the roof after excavation and backfilling of 1st pillar with fly ash

After filling the 1st pillar with fly ash, the stress is observed to be maxi-mum of 3MPa at pillars with more than 4MPa at the rib1. The displacement of the roof after the operation is calculated to be 10mm max.at places of pillar1 with magnitude of 7.5mm developed at other places of the same.

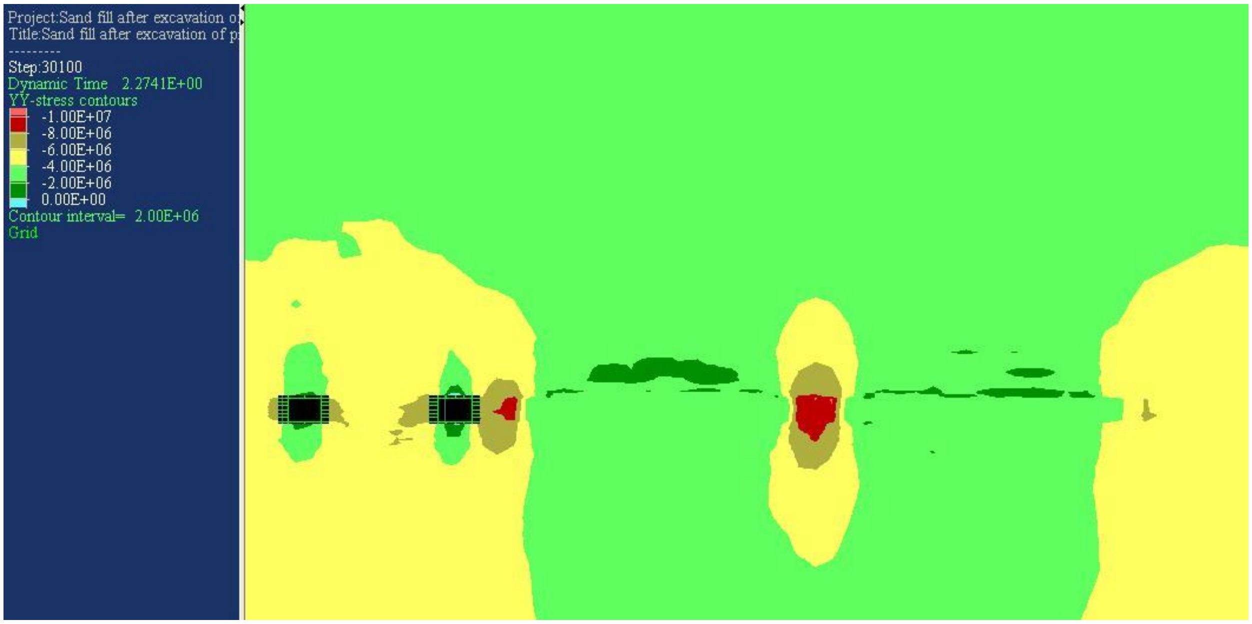


Figure 41: Stress distribution after extraction and backfilling of two pillars with fly ash

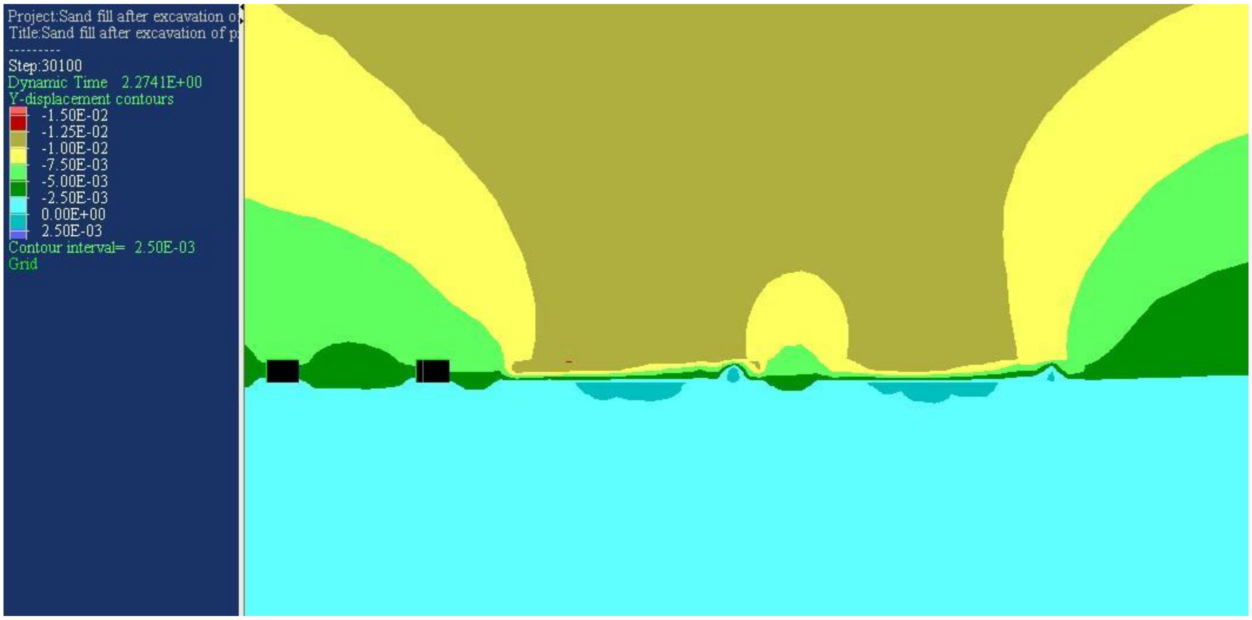


Figure 42: Displacement of the roof after excavation and backfilling of two pillars with fly ash

Stress developed in the pillars due to excavation and stowing of two pillars was found to be 4MPa. The displacement of the roof was found to be much higher at pillar 1and pillar 2 with magnitude maxi-mum of 15mm followed by pillar 3 with 6mm and rib 2 with 5mm.

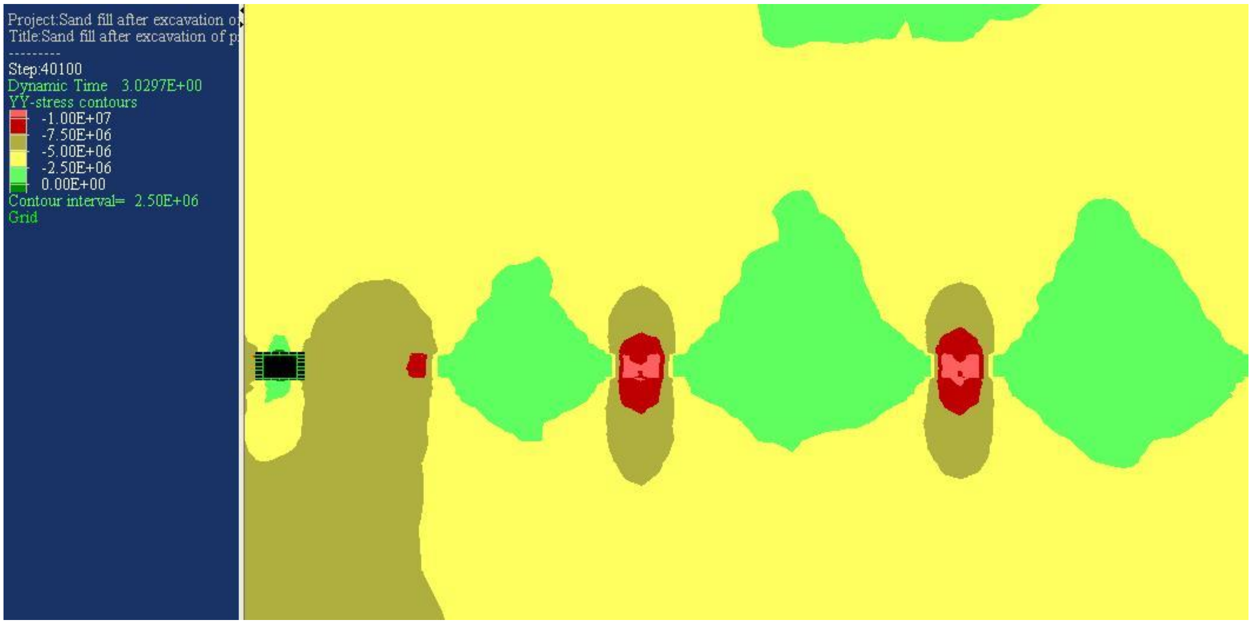


Figure 43: Stress distribution after extraction and backfilling of two and half pillar with fly ash with one rib left

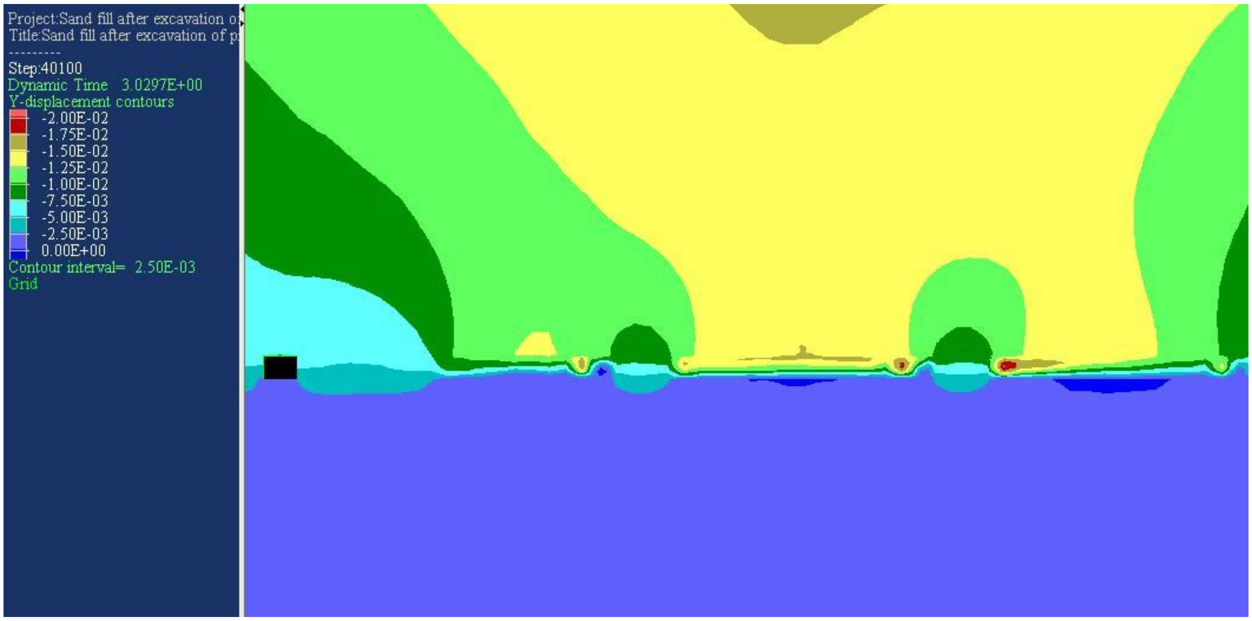


Figure 44: Displacement of the roof after excavation and backfilling of two and half pillar and one rib left with fly ash

Stress developed in the pillars due to excavation and stowing of two and half pillars was found to be 4MPa. The displacement of the roof was found to be much higher at pillar 1and pillar 2 with magnitude maxi-mum of 15mm followed by pillar 3 with 6mm and rib 2 with 5mm. There are some places where the deformation is around 20mm i.e. around the ribs.

Figure 45: Stress distribution after extraction and backfilling of 1st pillar with sand

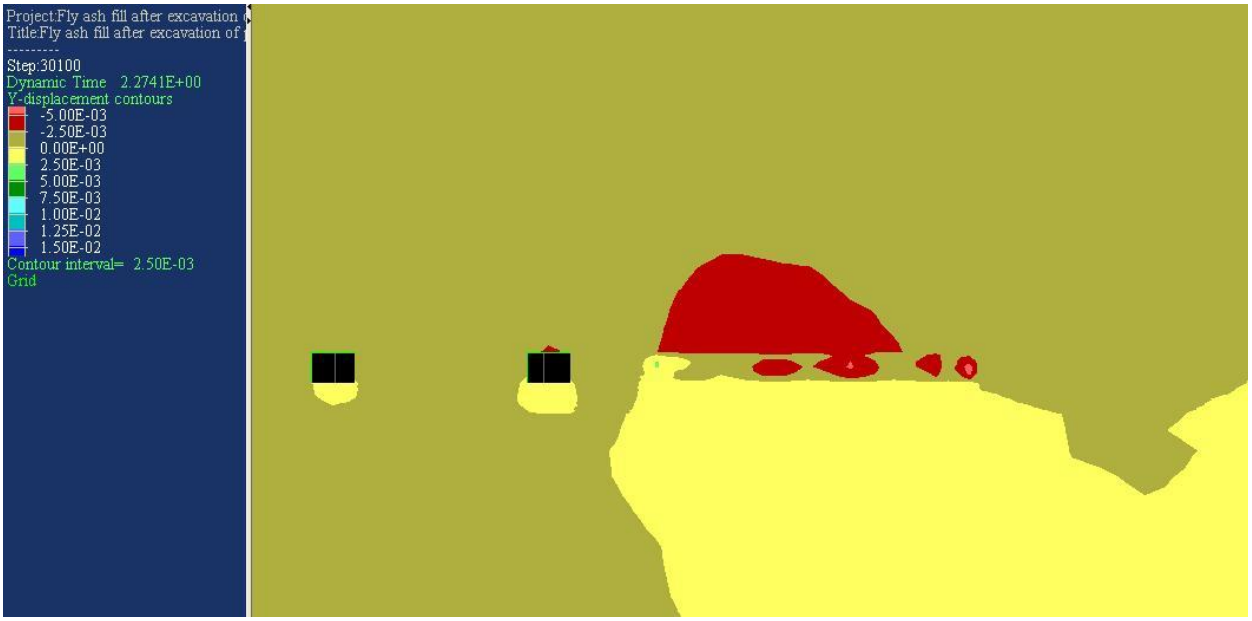


Figure 46: Displacement of the roof after excavation and backfilling of 1st pillar with sand

Maximum stress after stowing of 1st pillar was developed at rib1 with 6MPa whereas pillar3 and stook3 developed stress of 4MPa. Shrinkage of the stowed pillar1 with sand was found to be 20mm in cases of pillar 1 and rib 1.

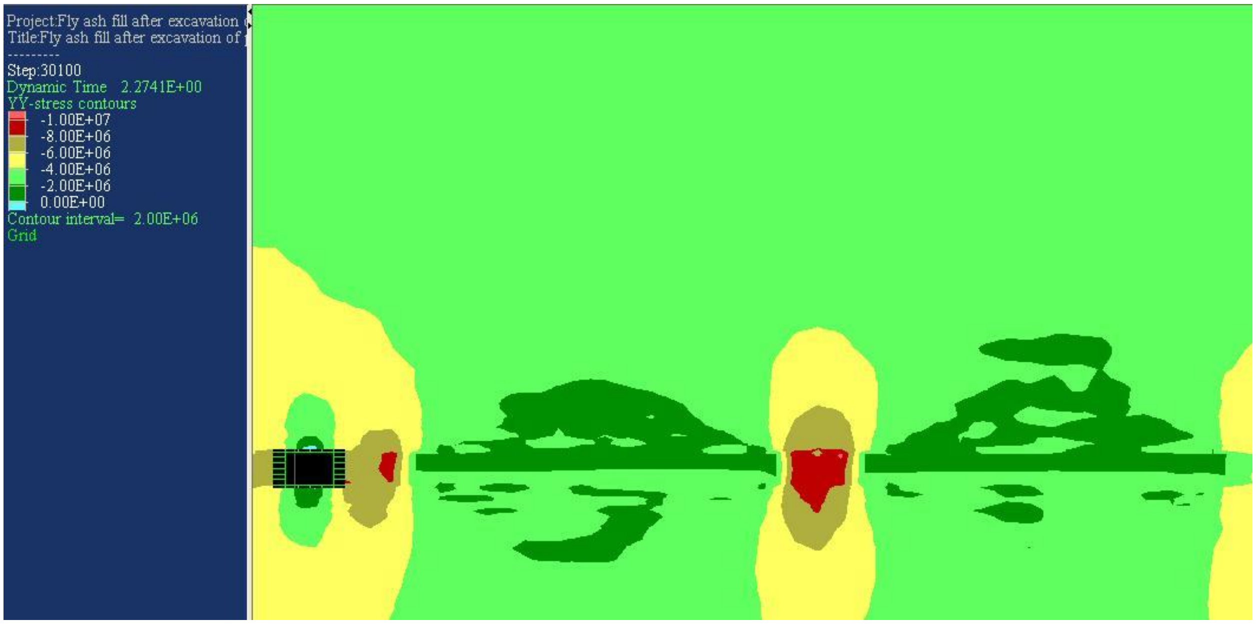


Figure 47: Stress distribution after extraction and backfilling of two pillars

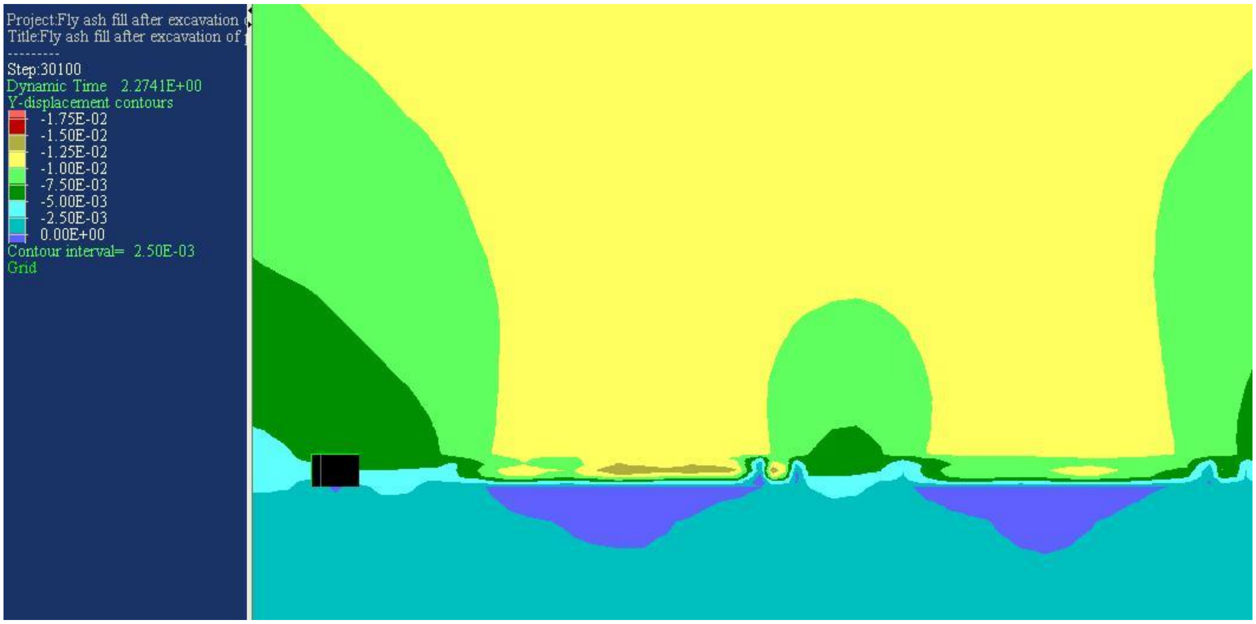


Figure 48: Displacement of the roof after excavation and backfilling of two pillars with sand

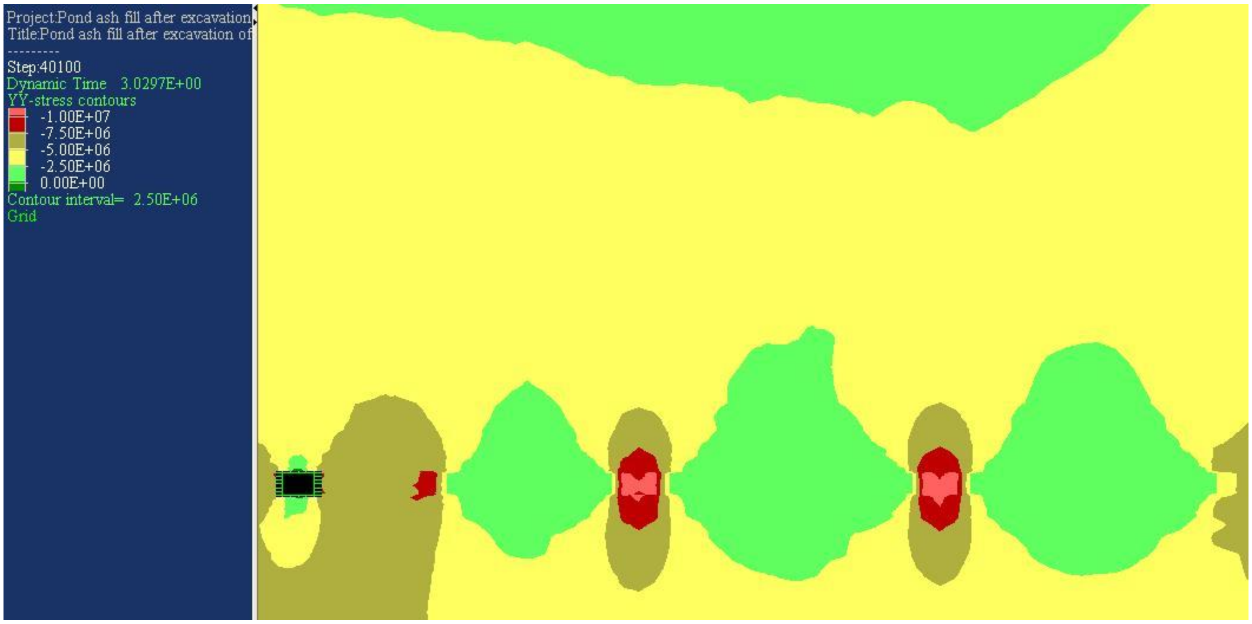


Figure 49: Stress distribution after extraction and backfilling of two and half pillars and one rib with sand

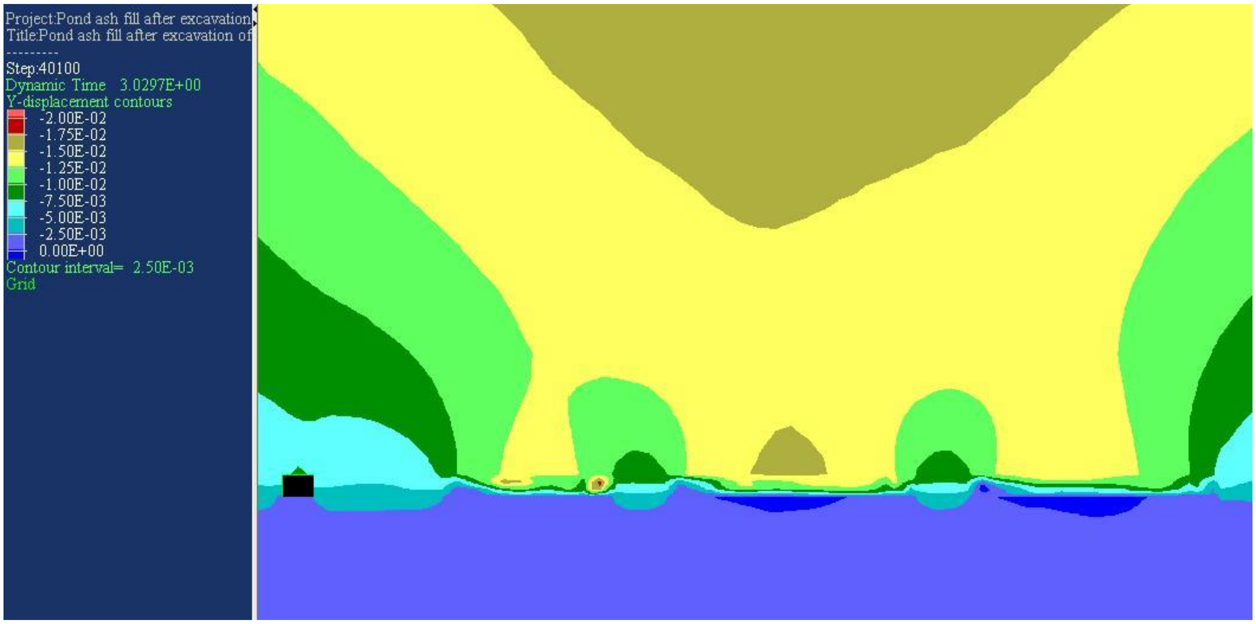


Figure 50: Displacement of roof after extraction and backfilling of two and half pillar with sand and one rib left

6.3 ANALYSIS:

FLAC simulation gave us with results that stowing with pond ash gave conditions with better stress distribution as well as less roof deformation. The shrinkage of the pond ash studies was indirectly studied by the heaving effect of the roof. After the excavation of 1st pillar the maximum stress is observed on the rib 1 i.e. around 8MPa. It is due to the It is seen that with pond ash the maximum roof deformation was around 5mm whereas without any fill it was 50mm, with fly ash it was 10mm and with sand mixture it was 20mm. Moreover the maximum stress after the excavation of pillars without fill was found out to be 20MPa whereas with pond ash fill the same was around 8MPa, with fly ash also 8MPa with sand also 8MPa. But there was more uniform distribution in cases of pond ash fill resulting in a more stable underground filling.

Fluent simulation of slurry transportation gave us with ideal velocity as well as volume fraction for pond ash so as to have minimum pressure drop in the pipes due to turbulence factor. When the velocity of the slurry was 3.5m/s less pressure drop was observed at the centerline as well as pipe-inner wall. Moreover as the concentration increases from 70% to 80%, pressure drop also increases to 17% which might be due to the fact that with increase in concentration, viscosity of the slurry increases and hence the effects of fluid friction, pipe friction and eddies formation. Increase in viscosity increase the activity among the different layers of the fluid which increases the friction. Keeping specific energy in view, the concentration of 70% of pond ash flowing at the rate of 3.5m/s can be economically conveyed through pipeline system with an estimated frictional drop of 1750 Pa/20m length of the pipe.

Table 11: FLAC SIMULATION STRESS DISTRIBUTION

Stages	Pillar 1	Rib 1	Pillar 2	Rib 2	Pillar 3	Stook
After EXCAVATION OF 1ST PILLAR						
Without any fill	2MPa	8MPa	4MPa	-	4MPa	6MPa
With Pond ash	2MPa	6MPa	4MPa	-	4MPa	6MPa
With Fly ash	2MPa	7MPa	5Mpa	-	4Mpa	4MPa
With Sand	2MPa	6MPa	2MPa	-	4MPa	4MPa
AFTER EXCAVATION OF TWO PILLARS						
Without any fill	2.5MPa	10MPa	2.5MPa	7.5MPa	5MPa	4MPa
With Pond ash	2MPa	8MPa	2MPa	7MPa	6MPa	6MPa
With Fly ash	2MPa	8MPa	2MPa	7MPa	5MPa	4MPa
With Sand	3MPa	8MPa	4MPa	7MPa	5MPa	4MPa

AFTER EXCAVATION OF TWO and HALF PILLARS						
Without any fill	2.5MPa	20MPa	2.5MPa	20MPa	2.5MPa	10MPa
With Pond ash	2MPa	2MPa	2MPa	2MPa	2MPa	3MPa
With Fly ash	1.5MPa	4MPa	1.5MPa	4MPa	1.5MPa	4MPa
With Sand	2MPa	4MPa	4MPa	4MPa	4MPa	5MPa
AFTER EXCAVATION OF TWO and HALF PILLARS WITH RIB						
Without any fill	5MPa	-	5MPa	-	5MPa	10MPa
With Pond ash	2MPa	-	2MPa	-	2MPa	3MPa
With Fly ash	1.5MPa	-	1.5MPa	-	1.5MPa	4MPa
With Sand	2MPa	-	4MPa	-	4MPa	5MPa

Table 12: Flac Simulation: Displacement Of Roof

Stages	Pillar 1	Rib 1	Pillar 2	Rib 2	Pillar 3	Stook
After EXCAVATION OF 1ST PILLAR						
Without any fill	15mm	10mm	10mm	-	10mm	10mm
With Pond ash	5mm	0	3mm	-	2mm	2mm
With Fly ash	10mm	8mm	5mm	-	3mm	3mm
With Sand	20mm	20mm	10mm	-	10mm	10mm
AFTER EXCAVATION OF TWO PILLARS						
Without any fill	20mm	20mm	20mm	20mm	20mm	20mm
With Pond ash	10mm	10mm	10mm	10mm	5mm	5mm
With Fly ash	15mm	15mm	15mm	10mm	3mm	3mm
With Sand	15mm	0	15mm	0	10mm	10mm
AFTER EXCAVATION OF TWO and HALF PILLARS						
Without any fill	40mm	25mm	40mm	25mm	40mm	25mm
With Pond ash	1mm	1mm	1mm	1mm	2mm	0
With Fly ash	6mm	6mm	8mm	5mm	6mm	2mm
With Sand	10mm	10mm	10mm	0	10mm	1mm
AFTER EXCAVATION OF TWO and HALF PILLARS WITH RIB						
Without any fill	50mm	-	50mm	25mm	50mm	25mm
With Pond ash	1mm	-	1mm	1mm	2mm	0
With Fly ash	6mm	-	8mm	5mm	6mm	2mm
With Sand	0	-	0	0	0	1mm

Vertical displacement of the roof after excavation of 1^{st} pillar is around 15mm without any fill whereas with pond ash it is observed to be around 5mm which is the least among other fill materials (fly ash -10mm and sand -20mm). Similarly vertical displacement in the second case is found to be 20 mm around stook, ribs and pillars whereas with pond ash it is around 10cm again least among other fill materials. With the last excavation of two and half pillars there is non-uniform deformation of the roof in case of no fill whereas it is around the magnitude of 2mm at all positions of the mine with pond ash.

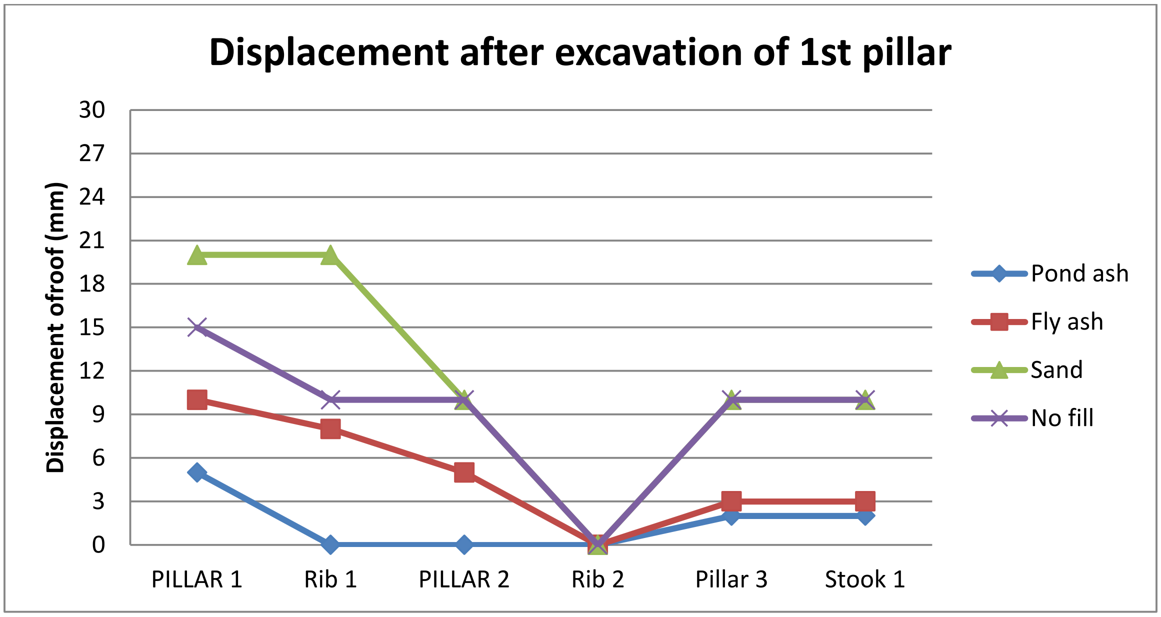


Figure 51: Displacement After Extraction Of 1st Pillar

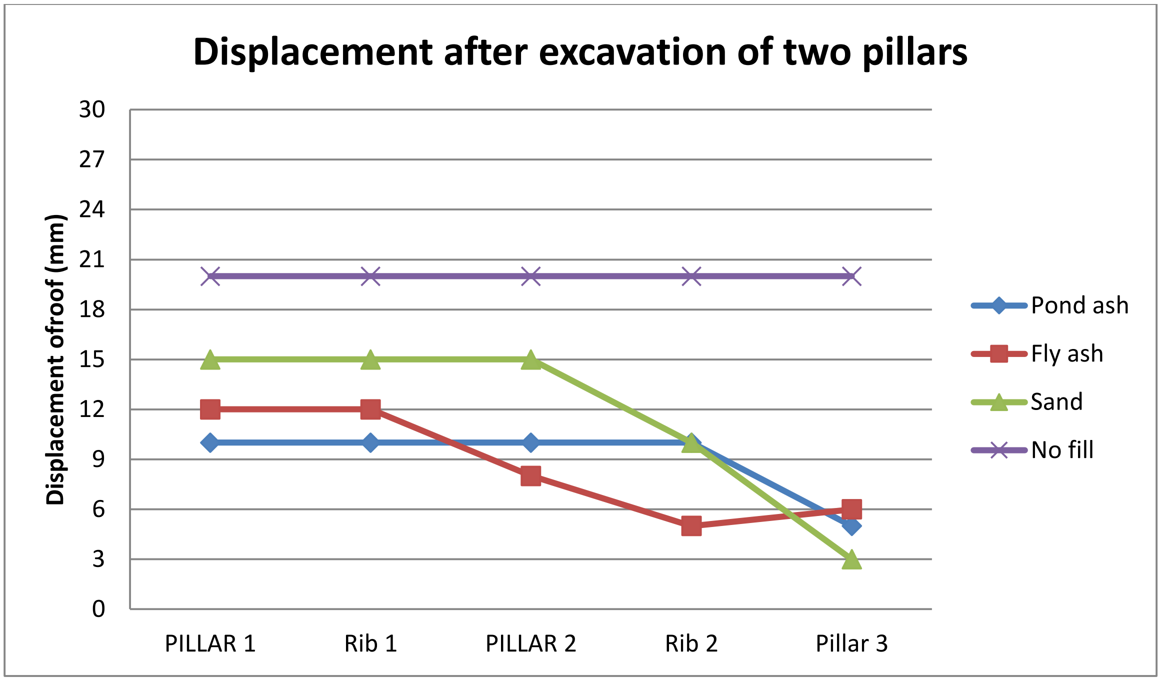


Figure 52: Shrinkage In Filled Area After Excavation Of Two Pillars

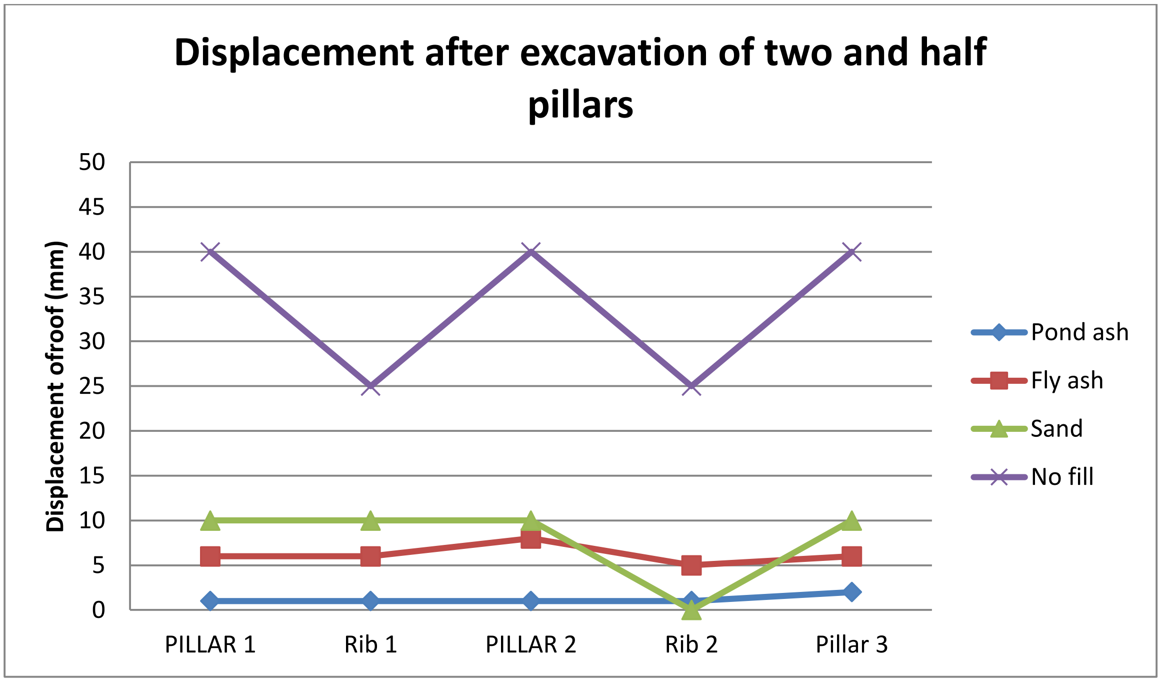


Figure 53: Shrinkage In Filled Area After Excavation Of Two And Half Pillars

CHAPTER – 7

CONCLUSIONS

From the analysis of flow behavior by CFD simulation, pond ash experimental studies and shrinkage studies by FLAC simulation, the followings can be concluded:

1. MDD ranges from 1.07gm/cc to 1.27gm/cc. With increase in compaction energy MDD increases which is due to the closer packing of pond ash particles.

2. With increase in compaction energy, OMC decreases from 38% to 28% approx. which might be due to the increase in moisture content leading to less friction between the particles and promoting compact packing with increase in compaction which in turn decreases voids and increase saturation limit.

3. The fluent simulation gave the settling rate for the sample which was found to be around 30% with water-liquid as phase 1 and pond-ash as phase 2.Velocity of the paste should be restricted to around 3.5m/s to reduce pressure drop. The volume fraction of the pond ash particles to be 70% by weight for better conveyance of the slurry.

4. The FLAC simulation of the roof conditions of data extrapolated from KTK-5 mine yields factor of safety (FOS) after excavation of one pillar with no fill to be 1.5 whereas with pond ash fill it is 2.7. Similarly FOS after stowing with pond ash in the voids of two pillars was found to be 2.5 whereas without fill it was 1.2. After excavation of two and half pillars FOS was calculated to be 1.9 with pond ash fill and 1.0 without fill.

REFERENCES

- http://cimfr.nic.in
- http://cdlab2.fluid.tuwein.ac.at
- http://carbomec.com.br
- Bunn T.F and Chambers A.J, “Experiences with dense phase hydraulic conveying of point fly ash”, International journal of power handling and processing, Vol. 5, No.1, pp. 35-44, (1993)
- TaimoorAsim, Rakesh Mishra and SumanPradhan, “A study on optimal sizing of pipeline transporting equi-sized particulate solid-liquid mixture”, University of Huddersfield Repository, (2012).
- Jesse Capecelatro and Olivier Desjardins, “Eulerian–Lagrangian modeling of turbulent liquid–solid slurries in horizontal pipes”, International journal of multiphase flow 55 64-79, (2013).
- Tamer Nabil, Imam El-Sawaf and Kamal El-Nahhas, “Computational fluid dynamics simulation of the solid-liquid slurry flow in a pipeline”, Seventeenth international water technology conference, IWTC 17, Istanbul, (2013).
- Gillies R. G and Shook C. A, “Modelling high concentration settling slurry flows”, The Canadian journal of chemical engineering, Vol. 78, pp. 709-716, (2000).
- ANSYS Fluent Theory Guide (2011), 14th release, ANSYS Inc., Canonsburg, Pennsylvania
- Davis, M.R. and Fungtamasan, B. (1990): Two-phase Flow Through Pipe Branch Junctions. International Journal of Multiphase Flow, Vol. 16, No. 5, January 1990, pp. 799-817.
- Fourie A.B, Copeland A.M and Barrett A.J, “Optimization of the as-placed properties of hydraulic backfill”, The Journal of The South African Institute of Mining and Metallurgy, August 1994, pp. 199-209.
- Sunil Chandel, S. N. Singh and V. Seshadri, “Transportation of high concentration coal ash slurries through pipelines”, International archive of applied sciences and technology Vol. 1 [1], (2010).

ANNEXURE -1

SIMULATION RESULTS: Input Data

Fluent: Release: 15.0.0

Version: axi, dp, pbns, eulerian, lam (axi, double precision, pressure-based, Eulerian, laminar)

MODELS

Model	Settings
Space	Axisymmetric
Time	Steady
Viscous	Laminar
Heat Transfer	Disabled
Solidification and melting	Disabled
Species	Disabled
Coupled Dispersed phase	Disabled
NO_x pollutants	Disabled
SO_x pollutants	Disabled
Soot	Disabled
Mercury Pollutants	Disabled

BOUNDARY CONDITIONS

Name	Id	Type
Centerline	8	Wall
Inlet	5	Velocity-inlet
Outlet	6	Pressure-outlet
Pipe-wall	7	Wall

Fluid Condition	Value
Material Name	Air
Specify source terms	No
Specify fixed values	No
Fixed Values	0
Motion Type	0
X-Velocity of Zone	0
Y-Velocity of Zone	0
Rotation speed	0
X-Origin of Rotation-Axis	0
Y-Origin of Rotation-Axis	0
Deactivated Thread	No
Porous zone	No
Porosity	1
Wall Condition	Value
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone	Yes
Apply rotational velocity to this wall	No
Velocity Magnitude	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Define wall velocity components	No
X-Component of Wall Translation	0
Y-Component of Wall Translation	0
Rotation Speed	0

OutletCondition	value
Gauge Pressure	18000
BackflowDirectionSpecificationMethod is	1
zoneusedinmixing-planemodel	No
Specifytargetedmass-flowrate	No
Targetedmass-flow	1

MATERIAL PROPERTIES:

Material: Pond-ash (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1900
Cp(SpecificHeat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4

Material: Water-liquid

Property	Units	Method	Value(s)
Density	kg/m3	constant	998.20001
Cp(SpecificHeat)	j/kg-k	constant	4182
Thermal Conductivity	w/m-k	constant	0.6
Viscosity	kg/m-s	constant	0.001003
MolecularWeight	kg/kgmol	constant	18.0152
Degrees ofFreedom		constant	0

ANNEXURE – 2

SAMPLE NUMERICAL MODEL PROGRAM FOR THE FLAC SIMULATION

```
TITLE
SHRINKAGE ANALYSIS IN THE BACKFILLED PILLARS IN MINE
*PROGRAM DEVELOPED BY JYOTI PRAKASH SAHOO
* Seam thickness=5.5m, Pillar size=30m, Depth=160m
* Gallery size=4.2m X 3m
GR 87 44
M M
*
*FLOOR OF THE MODEL
gen 0,0 0,40 40,40 40,0                               R .8 .8 I 1 10 J 1 10
gen 40,0 40,40 44.2,40 44.2,0                              R 1 .8 I 10 14 J 1 10
gen 44.2,0 44.2,40 79.2,40 79.2,0                          R 1 .8 I 14 31 J 1 10
gen 79.2,0 79.2,40 83.4,40 83.4,0                          R 1 .8 I 31 35 J 1 10
gen 83.4,0 83.4,40 118.4,40 118.4,0                            R 1 .8 I 35 52 J 1 10
gen 118.4,0 118.4,40 122.6,40 122.6,0                          R 1 .8 I 52 56 J 1 10
gen 122.6,0 122.6,40 157.6,40 157.6,0                      R 1 .8 I 56 73 J 1 10
gen 157.6,0 157.6,40 161.8,40 161.8,0                      R 1 .8 I 73 77 J 1 10
gen 161.8,0 161.8,40 201.8,40 201.8,                           R 0.8 .8 I 77 88 J 1 10
*
*Coal seam -5.5m
gen 0,40 0,45.5 40,45.5 40,40                             R .8 1 I 1 10 J 10 21
gen 40,40 40,45.5 44.2,45.5 44.2,40                       R 1 1 I 10 14 J 10 21
gen 44.2,40 44.2,45.5 79.2,45.5 79.2,40                   R 1 1 I 14 31 J 10 21
gen 79.2,40 79.2,45.5 83.4,45.5 83.4,40                   R 1 1 I 31 35 J 10 21
gen 83.4,40 83.4,45.5 118.4,45.5 118.4,40                 R 1 1 I 35 52 J 10 21
gen 118.4,40 118.4,45.5 122.6,45.5 122.6,40               R 1 1 I 52 56 J 10 21
gen 122.6,40 122.6,45.5 157.6,45.5 157.6,40               R 1 1 I 56 73 J 10 21
gen 157.6,40 157.6,45.5 161.8,45.5 161.8,40               R 1 1 I 73 77 J 10 21
```

```
gen 161.8,40 161.8,45.5 201.8,45.5 201.8,40                    R 0.8 1 I 77 88 J 10 21
*
* Sandstone roof-60m
gen 0,45.5 0,205.5 40,205.5 40,45.5                      R .8 1.2 I 1 10 J 21 45
gen 40,45.5 40,205.5 44.2,205.5 44.2,45.5                      R 1 1.2 I 10 14 J 21 45
gen 44.2,45.5 44.2,205.5 79.2,205.5 79.2,45.5                  R 1 1.2 I 14 31 J 21 45
gen 79.2,45.5 79.2,205.5 83.4,205.5 83.4,45.5                  R 1 1.2 I 31 35 J 21 45
gen 83.4,45.5 83.4,205.5 118.4,205.5 118.4,45.5                R 1 1.2 I 35 52 J 21 45
gen 118.4,45.5 118.4,205.5 122.6,205.5 122.6,45.5              R 1 1.2 I 52 56 J 21 45
gen 122.6,45.5 122.6,205.5 157.6,205.5 157.6,45.5              R 1 1.2 I 56 73 J 21 45
gen 157.6,45.5 157.6,205.5 161.8,205.5 161.8,45.5              R 1 1.2 I 73 77 J 21 45
gen 161.8,45.5 161.8,205.5 201.8,205.5 201.8,45.5                  R 0.8 1.2 I 77 88 J 21 45

PROP S=42E9 B=6.67E9 D=2100 T=9E6 C= 6.75E6 FRIC=45         I 1 87 J 1 9
PROP S=4E9 B=6.67E9 D=2100 T=9E6 C= 6.75E6 FRIC=45          I 1 87 J 21 44
PROP S=2.2E9 B=3.67E9 D=1480 T=1.86E6 C=1.85E6 FRIC=30     I 1 87 J 10 20
PROP S=1.4E9 B=2E9 D=1650 T=6000 C=5000 FRIC=17             I 1 87 J 17

*******BACKFILL WITH POND ASH PROPERTIES************
PROP S=5E5 B=1.33E6 D=1900 T=0 C=4E3 FRIC=31                        I 59 76 J 16 21
PROP        S=5E5        B=1.33E6        D=1900        T=0        C=4E3        FRIC=31
```

```
I 38 55 J 16 21
PROP S=5E5 B=1.33E6 D=1900 T=0 C=4E3 FRIC=31                I 22 34 J 16 21

SET GRA 9.81
set large
FIX X I 1
FIX X J 1
FIX X I 88
FIX Y J 1
INI SYY -3.38E6 VAR 0 3.38E6
INI SXX -1.45E6 VAR 1.45 1.45E6
HIS NSTEP 10
*Development galleries 4m x 3m
HIS UNBAL I 1 J 1
********************OPENING OF GALLERY 1***********
MOD NULL I 10 13 J 16 21
********************OPENING OF GALLERY 2***********
*MOD NULL I 31 34 J 16 21
********************OPENING OF GALLERY 3***********
*MOD NULL I 52 55 J 16 21
********************OPENING OF GALLERY 4***********
*MOD NULL I 73 76 J 16 21


********************OPENING OF SPLIT 1***********
*MOD NULL I 22 23 J 16 21
********************OPENING OF SPLIT 2***********
*MOD NULL I 42 43 J 16 21
********************OPENING OF SPLIT 3***********
*MOD NULL I 63 64 J 16 21
********************Excavation of PILLAR 1********
```

```
*MOD NULL I 59 76 J 16 21
********************Excavation of PILLAR 2********
*MOD NULL I 38 55 J 16 21
********************Excavation of PILLAR 2.5********
*MOD NULL I 22 34 J 16 21

********************AFTER JUDICIOUS RUB and BURST OF RIB 1********
*MOD NULL I 55 59 J 16 21

S=100
SAVE paf.sav
```