Department of Mining Engineering
Indian Institute of Technology
Kharagpur – 721 302

SURFACE SUBSIDENCE POTENTIAL DUE TO STOPING OPERATION AT NARWAPAHAR MINE, UCIL

Final Report

Submitted by

Prof. (Dr.) D. Deb

April, 2015

Table of Contents

Executive Summary 2

Objectives of the Project 5

1. Introduction 5

2. Subsidence Potential over the Stoping Operation at Narwapahar Mine 6

2.1. Definition of Key Components of Surface Subsidence 6

2.2. Components of surface movement 6

3. Surface Subsidence and Vertical Displacements 7

3.1 The Finite Element Method 7

3.2 Finite Element Modelling of Stopes 8

3.3 Loading and Boundary Conditions 9

3.4 Two-dimensional Finite Element Models 10

3.4 Generation of Finite Element Meshed Models 14

3.5 Assumptions of Finite Element Modeling 16

3.6 Results and Discussions 16

3.6.1 Displacement Distribution in Roofs 17

3.6.2 Subsidence and Horizontal Strain on the surface 19

3.6.4 Displacement Distribution from 4th to 2nd level of Khundungri Lode 20

3.6.4 Subsidence and Horizontal Strain on the surface above Khundungri Lode 23

4. Summary and Recommendations 26

EXECUTIVE SUMMARY

Cut-and-Fill stoping with Post Pillar method of mining has been adopted at Narwapahar mine. The main-lode ore body in Narwapahar mine above 5th level (-60 mRL) is being extracted using cut-and-fill method of stoping with post pillars. This study focuses on the determining surface subsidence at Narwapahar mine while stoping operation is conducted from 7th level (- 155 mRL) to 5th level (- 60 mRL) Spatially, the ore body is irregular in shape having variable thickness ranging between 5 m and 40 m. The strike length of the ore body is around 750 m at 6th level in Lode No. 3, the ore body has a strike length of about 350 m and has a dip of about 39° and is being extracted concurrently with the main lode. It extends vertically from 6th level to 2nd levels. Stopes from 3rd level to 2nd level have already been extracted and filled. The horizontal width of the ore body varies from 10 m to about 12 m. The minimum true thickness of the parting between main lode and Lode No. 3 is around 16 m and it is occurring in between level 6th and level 7th. Above 6th level, both lode diverge from each other.

Altogether, a total of 10 numbers of boreholes of diameter 36 mm and length of approximately 15 m, at various specified locations in 6th level of the main-lode ore body were drilled by the Uranium Corporation of India Ltd. (UCIL), using diamond drilling technique. These rock cores were transported to the Dept. of Mining Engineering, IIT-Kharagpur. RQD and recovery factor of the cores were estimated at every coring locations of the drill hole sample point. The material properties of the rocks used in the models were determined at the rock mechanics laboratory of the Mining Engineering Dept., IIT Kharagpur. Rock-joint survey was conducted at 5th and 6th levels and geological strength index (GSI) of rock mass was determined at various locations on the exposed roof and sides of the levels.

Two-dimensional (2-D) finite element modelling (FEM) techniques had been applied for designing the dimensions of the 'cut-and-fill stopes', size of the 'post pillars' and 'width of crown/ sill pillars' of main lode ore body at the Narwapahar mine of UCIL. A two-dimensional section of the widest part of the ore body, the most representative ones of the stope (resembling W16 area), is chosen for the study. Along this section, altogether 3 models were developed, viz. one insitu model and 2 models at two different mining stages. These models were considered for 'post pillar size of 5 m x 5 m at a room width of 8 m. The said section was considered for the analysis of stability of cut and fill stoping area, post pillars and crown/ sill pillars.

Three-dimensional finite element modelling techniques (3-D FEM) have been applied for designing stopes at Khundungri lode at Narwapahar mine. Numerical model is analyzed for 4 different mining

stages with 12 m width of rib pillar. This thickness of the ore body is around 6 m. The material properties used in the modelling are assumed from the laboratory tested rock materials and in-field investigation of GSI from an earlier project work conducted by the PI.

The following conclusions and recommendations are drawn from this study of surface subsidence:

1) As mentioned earlier, cut-and-fill stope with post pillars have been analyzed using finite element method (FEM). From this study, the vertical displacement profiles after stage-2 mining sequence (during last slice of stope advancing from 7th to 6th level and completed stope between 4th and 3rd level) depict that a maximum of 10 mm displacement can occur around the stoping area which reduces to 2 ~ 5 mm over the post pillars. This signifies that post pillars are absolutely necessary to protect the roof from excessive sagging. The main reason for this magnitude of displacement is due to yielding of roof rocks and high horizontal stress. However, vertical displacement can be reduced significantly if rock bolting is practiced properly.

2) The maximum surface subsidence due to stoping operation at Narwapahar mine (up to 7th Level) would be 10 mm with a similar elastic rebound. In this study, simultaneous operation of lode 3 and main lode is assumed. The data show that subsidence potential is minimal since cut-and-fill operation with post pillar method is being practiced in these lodes.

3) The maximum horizontal strain in compression and tension are found to be 0.12 mm/m and 0.02 mm/m which are far below the threshold of 10 mm/m. Hence, the proposed method of mining i.e. cut-and-fill with post pillar is safe method as far as surface subsidence potential is concerned.

4) The maximum surface subsidence due to stoping operation over Khundungri lode would be 2 to 3 mm with a similar elastic rebound. The width of the lode is too narrow to cause any substantial impact on the ground. Again, the data show that subsidence potential is minimal since cut-and-fill operation with post pillar method is being practiced in these lodes.

5) The maximum horizontal strain in compression and tension over Khundungri lode are found to be 0.03 mm/m and 0.01 mm/m which are far below the threshold of 10 mm/m. Hence, the proposed method of mining i.e. cut-and-fill with post pillar is safe method as far as surface subsidence potential is concerned.

Finally, it may be noted that this study is not conducted to analyze the effect of a particular joint plane or shear zone on the stability of the stopes, rather it provides an overall study of stress conditions and stability assessment of the stoping area. In addition, this study does not consider the dynamic loading conditions that may occur due to blasting.

Further, it is recommended that the mine management must be vigilant for any particular weak zone, fractured zone or disturbed zone, in the stoping area, and take necessary precautionary measures to improve the ground conditions towards safe mining practices.

Prof. (Dr.) Debasis Deb,
Principal Investigator

Department of Mining Engineering,
IIT, Kharagpur – 721 302
April, 2015

Dr. Debasis Deb
Professor
Dept. of Mining Engineering
Indian Institute of Technology
Kharagpur-721302, India

OBJECTIVES OF THE PROJECT

The project has two main objectives. They are as follows:

1) Determination of vertical displacement over stoped out area.
2) Determination of surface subsidence potential and horizontal strain on the surface

1. INTRODUCTION

The main-lode of ore body at Narwapahar mine is to be mined from 7th level to 5th level using cut- and-fill mining method with post pillars. The shape of the ore body is irregular having variable thickness ranging between 5 m and 40 m. The strike length of the ore body is around 750 m at 6th level. In the models, stopes between 4th level at 150 ml (-15 mRL) and 5th level are also incorporated. In this study, surface is taken to be at 135 mRL. Lode No. 3 ore body has a strike length of about 350 m and has a dip of about 39° and is being extracted concurrently with the main lode. It extends vertically from 6th level to 2nd levels. Stopes from 3rd level to 2nd level have already been extracted and filled. The horizontal width of the ore body varies from 10 m to about 12 m. The minimum true thickness of the parting between main lode and Lode No. 3 is around 16 m and it has occurred in between level 6th and 7th. Above 6th level, both lode diverge from each other.

The PI had conducted an earlier project where rock cores were obtained from 4 boreholes drilled at various locations along the drives at 240 ml or -105 mRL. Rock quality designation (RQD) and recovery factors had been calculated at the coring site and the cores were transported to Department of Mining Engineering, IIT-Kharagpur. Various geomechanical parameters such as compressive strength, tensile strength, elastic modulus, Poisson's ratio, density and other parameters had been tested in the rock mechanics laboratory of the Department of Mining Engineering.

In this study, two-dimensional (2-D) numerical modelling has been performed to obtain surface subsidence at Narwapahar mine, UCIL, along the widest part of the ore body, the most representative ones of the stope. The numerical model section also contains Lode No. 3 ore body from below 7th level to 2nd level. Altogether 3 models were developed, one insitu model and 2 models at the two different mining stages i.e. stopes in between 7th and 5th levels for 8 m room, with 5 m x 5 m pillar dimensions. Mining of Lode No. 3 from 5th level to 2nd level has also been incorporated into the models. In a meeting with the mine management, it was decided that 5 m x 5 m post pillar with 8 m room size would be the ideal combination for horizontal cut and fill stopes. In this study, stability analysis of stopes for simultaneous excavation of main lode and Lode No. 3 is investigated using numerical modeling approach. The material properties used in the modelling had been determined from the laboratory tested rock materials and on investigation/ examination of GSI/ RMR at the site.

Three-dimensional finite element modelling techniques (3-D FEM) have been applied for designing stopes at Khundungri lode at Narwapahar mine. Numerical model is analyzed for 4 different mining stages with 12 m width of rib pillar. This thickness of the ore body is around 6 m. The material

properties used in the modelling are assumed from the laboratory tested rock materials and in-field investigation of GSI from an earlier project work conducted by the PI.

2. SUBSIDENCE POTENTIAL OVER THE STOPING OPERATION AT NARWAPAHAR MINE

2.1. DEFINITION OF KEY COMPONENTS OF SURFACE SUBSIDENCE

Generally a particle on the surface move horizontally toward the centre of the subsidence basin, every particle in the basin also subsides vertically. The magnitude of subsidence increases toward the centre of the basin. Since subsidence and displacement vary continuously in every major cross-section, three deformation components are significant in determining the subsidence and damage potential of surface structures. They are vertical movement, horizontal movement and horizontal strain. These three components of the surface movement are defined as given below (**Figure 1**):

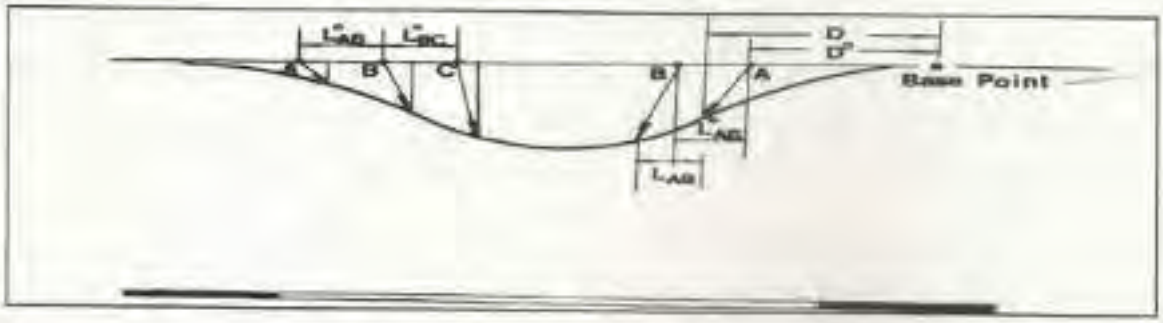


Figure 1. Definition of surface deformations

2.2. COMPONENTS OF SURFACE MOVEMENT

Subsidence (S): On any cross-section, the vertical component of the surface movement vector is called surface subsidence. It generally points downward. But sometimes it points upward in areas ahead of the extraction line or beyond the edges of the opening. In such case it is a surface heave which is usually less than 6 in. ($S = Z - Z^0$).

Displacement (U): On any cross-section, the horizontal component of the surface movement vector is called surface horizontal displacement. It generally points toward the centre of the subsidence basin. But in steep terrain, it moves along the down dip direction. ($U = D - D^0$).

Horizontal strain ($e = dU/dx$): On any cross-section, the difference in horizontal displacement between any two points divided by the distance between the two points is called horizontal strain. If the distance between the two points is lengthening, it is tensile strain with positive sign. Conversely, if it is shortening, it is compressive strain with negative sign. ($e = (U_A - U_B)/L_{AB}$). In general, 10 mm

horizontal displacement per every 1 m of horizontal distance or 1% strain is acceptable for surface structures in uninhabited area.

Results of this study will be focused on evaluation of these three parameters using numerical modelling techniques.

3. SURFACE SUBSIDENCE AND VERTICAL DISPLACEMENTS

3.1 THE FINITE ELEMENT METHOD

Finite element method (FEM) is an effective tool for the analysis of mechanical and structural components of machinery. This method is amenable to systematic computer programming and offers a scope for application to a wide range of analysis problems. This method is now adopted in almost all branches of engineering where complex structures, fluid dynamics problems, mine and tunnel structures and similar problems are addressed.

The basic concept in this approach is that a body or structure can be divided into a finite number of smaller units of finite dimensions called 'elements'. The original body or structure is then considered as an assemblage of these elements connected at finite number of joints called 'nodes' or 'nodal points'. The properties of these elements are formulated and combined to obtain the solution for the entire body or structure. The global system of equations is developed as follows:

$$\{F\} = [K]\{q\} \quad \dots \quad \dots \quad \dots \tag{1}$$

Where, (F) = global force vector, i.e. forces in each node,

[K] = global stiffness matrix based on material properties,

(q) = displacement vector containing each node.

Necessary (essential) boundary conditions in terms of displacements at some selected nodes are applied before solving this system of equations. For structural analysis problems, the equations of equilibrium for the entire structure or body are obtained by combining the equilibrium equations of each element such that the continuity of the displacement is ensured at each node where the elements are

connected. The necessary boundary conditions are then imposed and the equations of equilibrium are solved for the nodal displacement. Using these values of displacements at the nodes of each element, the strains and stresses are evaluated for each element using their properties.

3.2 FINITE ELEMENT MODELLING OF STOPES

For this study, various longitudinal-vertical sections, transverse sections and plan view of the mine maps of the region between the 7th, 6th 5th and 4th levels have been provided by the Narwapahar mine of UCIL. **Figure 2A** shows the plan view of main lode, lode 3 at this mine and also depicts the drives, crosscuts and the extent of ore body at different RLs for the main lode.

From the given mine plans, information regarding the spatial properties of the ore body viz., the width, dip, proposed stope locations and other geometrical data were extracted. All these information have been very valuable for developing varieties of numerical models. In this study, the widest part of the ore body has been analyzed including post pillars, filled zone and crown/ sill pillars.

Figure 2A. Plan of the region showing geotechnical borehole locations and the model section.

The aforesaid ore bodies are planned to be mined out using cut-and-fill method with post pillar stoping techniques. This study focuses on the assessment of the stability of the cut-and-fill stopes and determination of safety factor of the post pillars under various geo-mining conditions. In this report,

two-dimensional finite element models are developed along model section (**Figure 2A**) and the results of the analyses are elaborated below.

Figure 2B shows the plan view of 2nd and 4th levels of Khundungri lode depicting drives and crosscuts. From these maps, information regarding the ore width, dip, proposed stope locations and other geometrical data were extracted. Information about the stope dimensions, average width of rib pillars, crown pillars etc. was also procured from UCIL. All these information had been very valuable for developing the variety of numerical models.

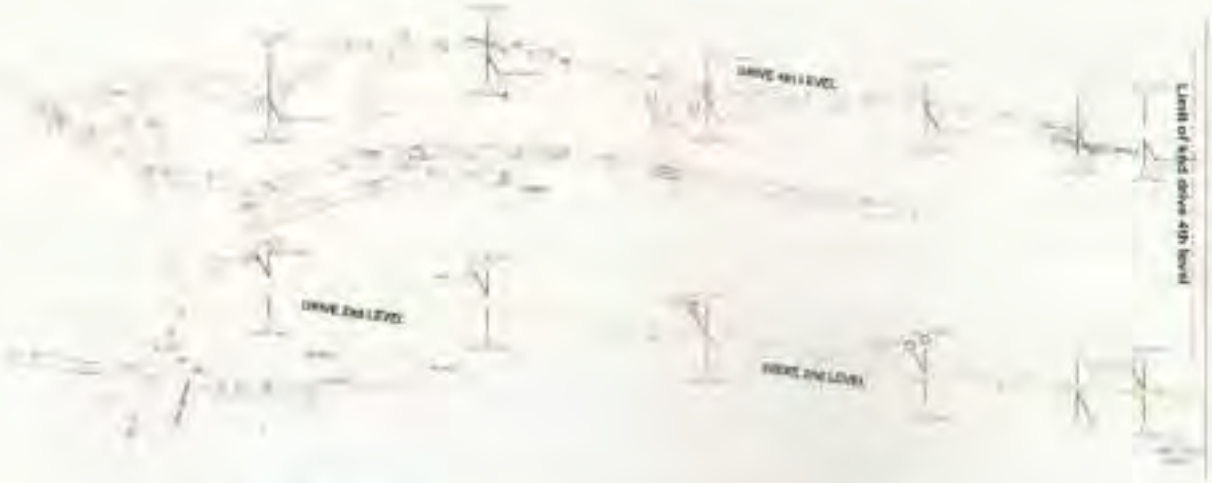


Figure 2B. Plan of the region showing geotechnical borehole locations.

The region is planned to be mined out using Cut-and-Fill stoping technique. This study focuses on the assessment of the stability of the Cut-and-Fill stopes and determination of safety factor of crown pillar as well as rib pillar for different geo-mining conditions.

3.3 LOADING AND BOUNDARY CONDITIONS

The models are constrained from the bottom in vertical direction and one side in a direction perpendicular to strike and surface gradient pressure is applied form the opposite side. The applied sideways pressures are varied with the height of the model. The following equation is used for calculation of horizontal stress in finite element model according to depth of the ore body.

$$\sigma_H = 0.036325*H \qquad (1)$$

Where, σ_H : ~~h~~Horizontal stress (MPa),

H : Depth from the surface (m)

Gravitational force is applied on model as body force ($g = 9.81 m/sec^2$). **Figure 3** shows the load and displacement boundary conditions those are applied to the model boundaries.

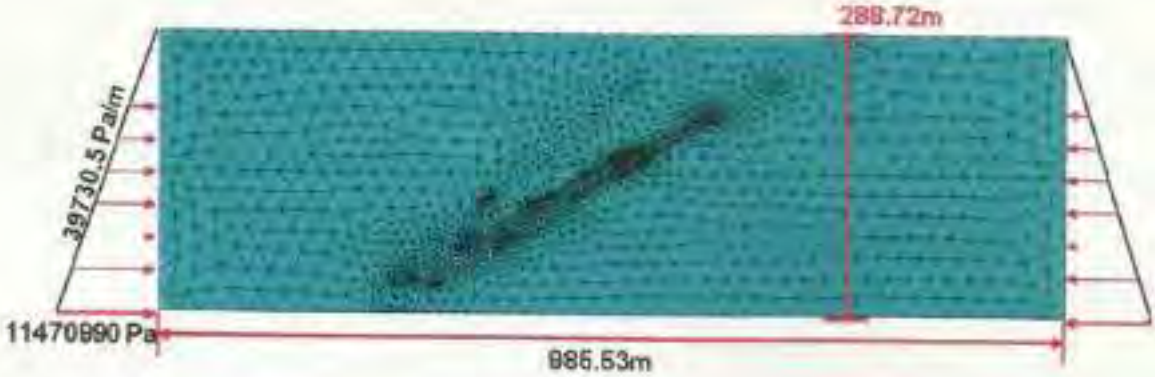


Figure 3. Meshed model showing loading and boundary conditions

3.4 TWO-DIMENSIONAL FINITE ELEMENT MODELS

Three Finite Element models were created for the assessment of the stability and the stresses developed in the region. Firstly, an insitu model is developed to estimate the elastic displacements prior to mining. It is also required to analyze how the stresses and safety factor vary as the mining activity proceeds simultaneously in main lode and lode no. 3. 2-D models were designed with the following general specifications:

Two dimensional models were made for 5 m (pillar width) x 8 m (room width) combination of pillar and room width. Stage-1 of mining operation is considered as a scenario when the stoping operation proceeds from 6th level to 5th level in the main lode and simultaneously stoping operation continues in lode no. 3 from 4th level to 3th level (**Table 1**). Similarly in Stage-2 of mining operation, the stoping operation in the main lode proceeds from 7th level to 6th level in concurrence with stoping from 5th level to 4th level in lode no.3. The geometry of the stopes changes after each cut and fill activities. To consider these dynamic activities, two models of varying geometries were developed corresponding to the sequence in which the mining will be done in this region. The mining activity is broken down into a series of 2 sequences for stoping block as given in **Table 1**.

Table 1. Stoping sequence for each block

Stages of mining	Activity in the Stope
0 (In-situ model)	No stoping at 6th and 7th levels of main lode and 5th and 4th levels of Lode No. 3.
Stage - 1	Filling of last horizontal slice in main lode between 6th and 5th levels is left and stopes between 5th and 2nd levels are backfilled. Filling of last horizontal slice in Lode No. 3 between 4th and 3rd levels is left and stope between 3rd and 2nd levels is backfilled.
Stage - 2	Filling of last horizontal slice in main lode between 7th and 6th levels is left and stopes between 6th and 2nd levels are backfilled. Filling of last horizontal slice in Lode No. 3 between 5th and 4th levels is left and stopes between 4th and 2nd levels are backfilled. Crown/ sill pillars of thickness 5 m are left at the bottom of both 5th and 6th levels. Crown/ sill pillar of thickness 5 m is left at the bottom of 4th level.

It may be noted that stoping operation has been started simultaneously in main lode and lode no. 3 in the upper levels. In these two stoping stages, several slices have already been taken and filled before abandoning the stope without filling the last slice of stope. In these models, this mining activity has also been considered. Numerical models were developed for each of these stages. For stages 1 and 2, analysis is performed for pillar size 4 m and room width 8 m (5 m x 8 m). Thus, a total number of numerical models analyzed for determining the stope stability is (2 +1(insitu)=) 3. Description of the models is given below:

Model 0 : In-situ model

Model 1 : Pillar size = 5 m x 5 m. Room span 8 m, at mining stage 1.

Model 2 : Pillar size = 5 m x 5 m, Room span 8 m, at mining stage 2. Crown/sill pillars of 5 m thickness are left at the bottom of 5th and 4th levels.

Figures 3a to **3b** explain each stages of mining sequence that are considered in this study. Mechanical properties such as elastic modulus, Poisson's ratio, compressive and tensile strengths of the rocks, form the cores provided by UCIL, were estimated from various strength tests conducted in the laboratory at IIT in earlier project. The values obtained from the test were an estimate of the "intact rock material". In the field, rock mass is present with local cracks, fractures and discontinuities, which reduce the strength of the rock mass considerably. Hence, to incorporate this reduction in the rock strength, the rock properties were modified, according to the following equations:

$$\sigma_{cm} = (0.003m_i^{0.8})\sigma_{ci}(1.029 + 0.025e^{-0.1m_i})^{GSI} \quad \text{(2)}$$

Assuming that the strains developed in the rock mass and the core samples remain unchanged, elastic modulus can be further estimated as

$$E_c = (0.003m_i^{0.8})E_{ci}(1.029 + 0.025e^{-0.1m_i})^{GSI} \quad \text{(3)}$$

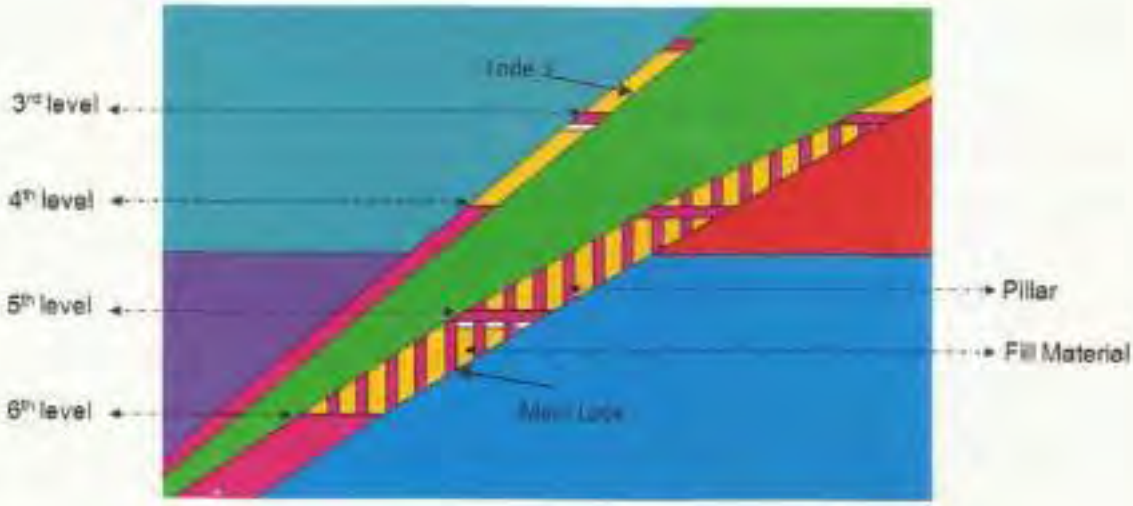
Again, considering the unforeseen events such as water conditions, local joints and fractures, elastic modulus of rock mass is further reduced to 80% as

$$E_{cm} = 0.8E_c \quad \text{(4)}$$

Here,

m_i = the Hoek-Brown parameter of intact rock,,
σ_{ci} = uniaxial compressive strength (Intact rock core),
σ_{cm} = uniaxial compressive strength (rock mass),
E_{ci} = elastic modulus (intact rock core),
E_c = elastic modulus (rock mass), and
E_{cm} = elastic modulus (reduced by 80%).

In this study, Poisson's ratio (ν) of intact rock and that of rock mass is kept the same. **Table 2** lists the rock and rock mass properties those are used for finite element modelling for different zones mentioned in **Figure 4**.



(a) model - 1

(b) model - 2

Figure 4. 2-D finite element models of the ore body along the model section

A 3-D model was designed for Khundungri lode with the following general specifications:

1) A total of 4 stopes were constructed into the model. Out of these two are there between the 2nd and 3rd Levels, the other 2 are there between the 3rd and 4th Level. A longitudinal model section is shown in **Figure 5** after the stoping operation is completed up to 2nd level and all the stopes are filled.
2) Stopes at each levels, are separated by a rib pillar of 12 m, thereby dividing the complete strike length of 450 meters into two halves of 219 m (plus the rib pillar length of 12 m)

3) A crown pillar of 5 m is left between the stopes at two horizons. Therefore, the total height of the stopes is: S1 = 25 m; S2 = 35 m.

4) A raise (of cross-section 2x2 m) is passing through the central Rib Pillar from 4th to 2nd levels.

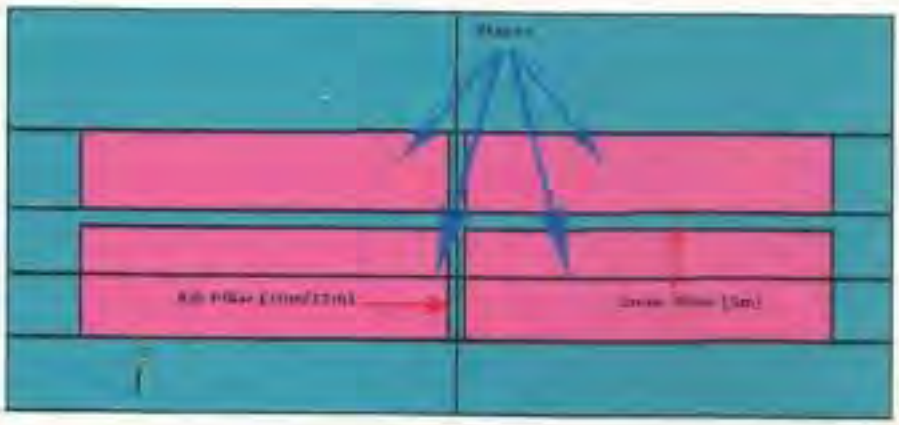


Figure 5. Longitudinal model section when stoping is completed up to 2nd level

3.4 GENERATION OF FINITE ELEMENT MESHED MODELS

The meshing of the complete model produced an average of around 6000 6-noded triangular elements and around 20,000 nodes. Little variations were noted in node counts with different model geometries. **Figure 6** shows the meshed model of ore-body and its surrounding areas. In general, finer mesh is developed around the cut-and-fill stoping zones. In those zones, finer mesh is required for better evaluation of displacements, stresses and strains. Coarse mesh is developed in the rock-body away from the mining-affected zones (zone of no-rock movement due to mining).

Table 2. Material properties used in the models

Zone		Elastic Modulus (GPa)	Poisson's ratio	GSI	Cohesion (MPa)	Angle of Internal Friction	Flow angle	Density (kg/m^3)
Hanging wall	Zone 1	5.23	0.1268	69	4.419	30	15	2700
	Zone 2	6.34	0.1280		7.500	30	15	2855

Zone	Elastic Modulus (GPa)	Poisson's ratio	GSI	Cohesion (MPa)	Angle of Internal Friction	Flow angle	Density (kg/m^3)
Footwall	Zone 3 2.82	0.0377	60	2.857	30	15	2700
	Zone 4 3.92	0.1230		4.920	30	15	2798
	Zone 5 5.34	0.1200	69	6.500	30	15	2700
Ore Body	4.06	0.1000	55	4.720	30	15	2924
Fill Material	0.40	0.3500	-	-	-	-	1800

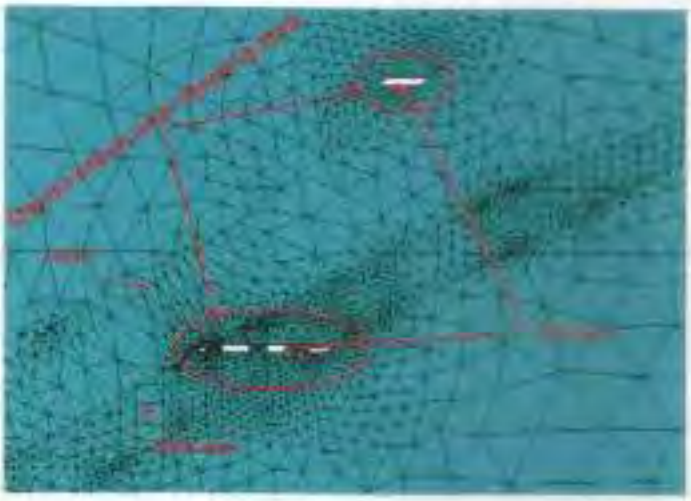


Figure 6: Finite element mesh showing ore body and neighbouring area.

The meshing of the complete Khundungri model produced an average of around 60,000 ten-noded tetrahedral elements and around 90,000 nodes (varying slightly with different model geometries). The complete meshed model (showing the dissection of hang-wall, foot-wall and ore-body) is shown in **Figure 7**.

In general, finer mesh is developed around the drives, raises and cut-and-fill stoping zones. In those zones, finer mesh is required for better evaluation of displacements, stresses and strains. Coarse mesh is developed in the body away from the mining effected zones.

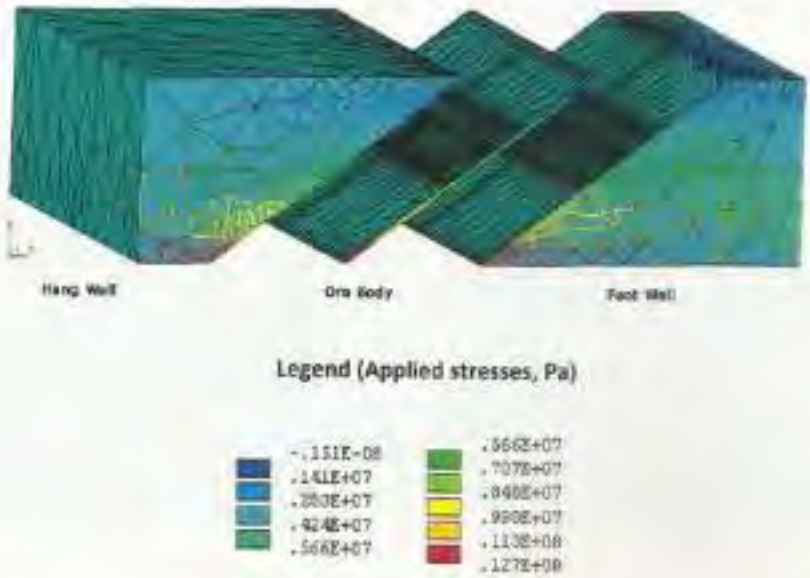


Figure 7: Finite element mesh showing HW, FW, ore body and contours for applied stresses.

3.5 ASSUMPTIONS OF FINITE ELEMENT MODELING

In this study, certain assumptions were made for the analysis of ground behaviour using finite element modeling. They are as follows:

- All finite element models are analyzed considering non-linear material behaviour. Drucker-Prager yield criterion is applied to determine the onset of yielding and then plastic corrections are applied to adjust stresses.
- Effect of joints and bedding planes are imbedded in RMR or GSI value of rock mass. The effect of a particular joint or bedding plane is not analyzed explicitly.
- No dynamic loading is applied in the model.

3.6 RESULTS AND DISCUSSIONS

All finite element models were analyzed based on non-linear elasto-plastic behaviour of rock materials. Drucker-Prager yield criterion has been applied to determine the onset of yielding. Results of finite

element analysis are obtained in terms of displacements, principal stresses and safety factors along the long axis of the pillar and ceiling of the roof. For each numerical model, principal stresses and displacements were calculated from each model separately. These values were calculated along the pre-decided linear paths in the models. The location of these paths was selected to highlight those regions of the model, which are most relevant to the properties being measured (**Figure 8**). Surface subsidence is estimated along the path E-E' line as shown in **Figure 9**.

(a) (b)

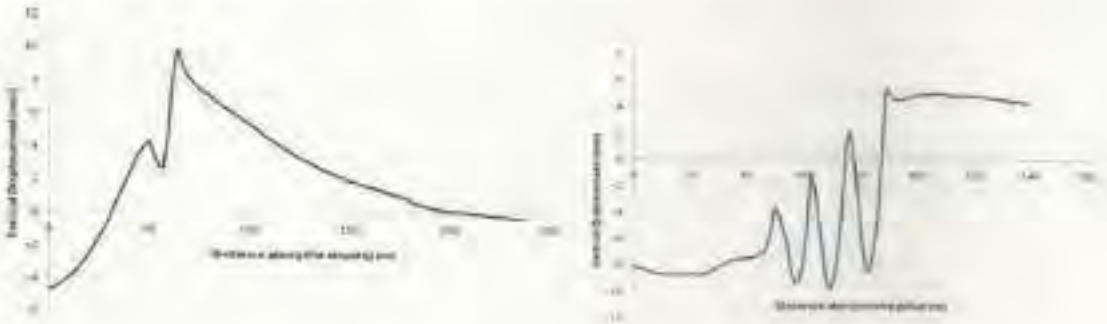
Figure 8. Paths of displacement measurements a) Stage-1 b) Stage-2

Figure 9. Paths of displacement measurements along surface EE

3.6.1 Displacement Distribution in Roofs

Vertical displacement profiles are calculated along two paths one at 30 mRL (Line: A-A') and other at -60 mRL (Line: B-B') for model - 1 mining sequence as shown in **Figure 8a**. The displacement data collected from the numerical model along these paths are subtracted by the in-situ displacement values of the corresponding paths. This was done in order to obtain the displacement caused due to the mining

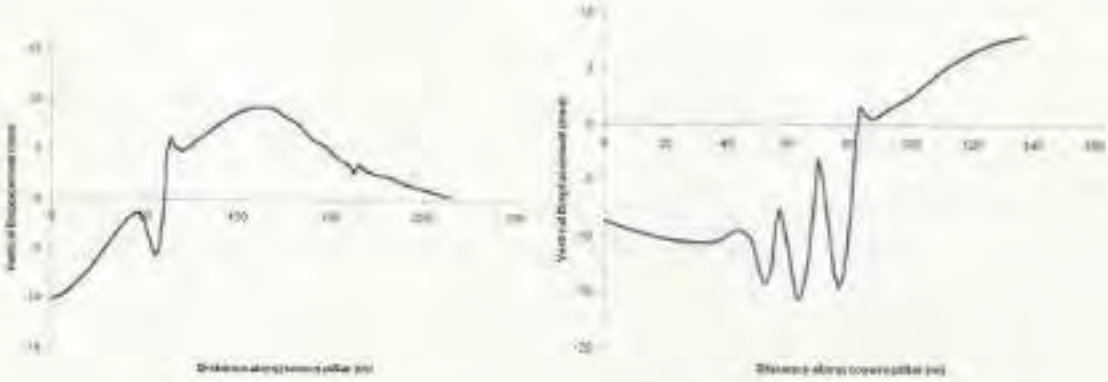
activities only. **Figure 10a** shows a maximum possible displacement of about 9.85 mm in the roof during the stoping operation at 30 mRL of lode 3. However, the vertical displacement reduces towards the filled stope of main lode and diminishes towards zero displacement. These deformations have occurred because the extent of stoping area is 12 m x 2.5 m at the end of last cut. On the contrary, when the stoping operation reaches at -105 mRL (below the crown pillar) in between 6th and 5th levels (**Figure 8b**), there is no stoping operation in lode 3. The maximum vertical displacement at top of the middle pillar of stope in main lode becomes 9.84 mm, whereas it is about 8 mm between the two lode (hanging wall). **Figure 10b** shows a maximum possible displacement of about 10.14 mm, 50 m away from lode 3 in footwall side and it comes down to 1.28 mm at the start of stope in lode no. 3. The maximum roof sagging of about 5.7 mm occurs in the middle of stope of lode 3. In the region of the hanging wall of lode 3 and the footwall of the main lode, the heaving of about 9.19 mm is observed. In case of stage -2 (or Model -2), vertical displacement profiles are calculated along two paths one at -15 mRL (Line: C-C') and other at - 105 mRL (Line: D-D') as shown in **Figure 8b**. The path line C-C' passes through the crown of level 5 and path line D-D' passes through the crown of level 7. On path D-D' as shown in **Figure 11b**, the vertical displacement in hangwall side of main lode is about 10 mm, whereas it is about 14.12 mm, 15.64 mm and 14.73 mm at the bottom of the roof area of the stope.



a. line A-A' for model -1

b. line B-B' for model -1

Figure 10. Vertical displacement profiles for model -1



a. line C-C' for model -2

b. line D-D' for model -2

Figure 11. Vertical displacement profiles for model -2

3.6.2 Subsidence and Horizontal Strain on the surface

Surface subsidence or vertical movement of the surface along E-E' line is plotted in **Figure 12a**. The figure shows that a maximum subsidence of 10 mm is expected when Stage-2 stoping operation is being conducted. Due to horizontal stress, an elastic rebound is expected in the middle of the Lode 3 and main lode which may cause tensile zone on the surface.

Horizontal strain denotes the potential for tensile and compression zone on the surface. The maximum compressional strain is found to be 0.12 mm/m and that of tensile strain is 0.02 mm/m (**Figure 12b**). These data show that effect of stoping operations on the surface is minimal.

Figure 12a. Vertical displacement profiles along line E-E

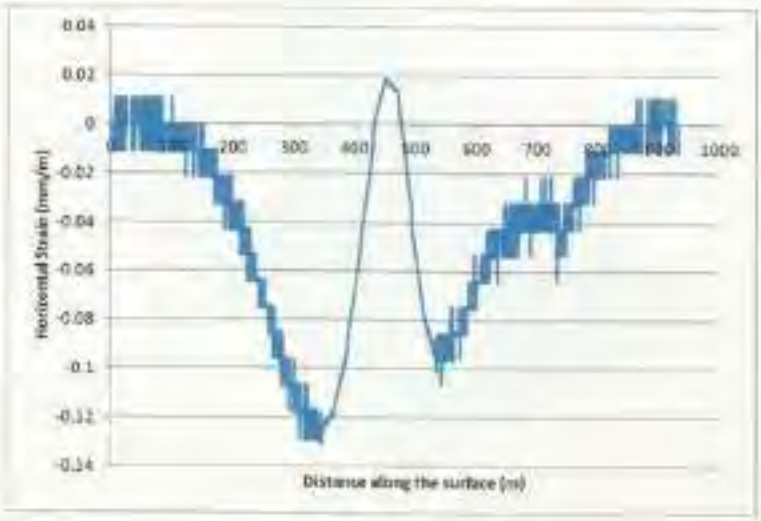


Figure 12b. Horizontal strain profiles along line E-E

3.6.4 Displacement Distribution from 4th to 2nd level of Khundungri Lode

Vertical displacement is measured along two paths (B-B' & C-C' line) crossing the stopes (lying between 2nd and 4th levels) exactly midway of the length, grazing the stopes along the hanging wall contact as shown in **Figure 13**. The displacement data collected from each model along these paths are subtracted by the in-situ displacement values of the corresponding paths. This was done in order to obtain only the displacement caused due to the mining activities. **Figure 14** shows the vertical displacement profiles along these paths when rib pillar width is 12 m. In these figures, legend 1, 2, 3 and 4 depict the stages of mining activities as described earlier.

It is clear from **Figure 14** that vertical displacement of the crown pillar above the 2nd level will be in the upward direction with a maximum value of 5 mm. This may cause since the horizontal stresses are assumed to be 2.0 and 1.4 times that of vertical stress. On the contrary, the maximum downward vertical displacement of 4.2 mm may occur just above the 4th level. It can also be inferred that there is no significant change in vertical displacements along these two paths for the models having 12 m rib pillar. Finally, the vertical displacement profiles along the roof of the stopes show no major ground movement around the stoping area for any stages of mining activities.

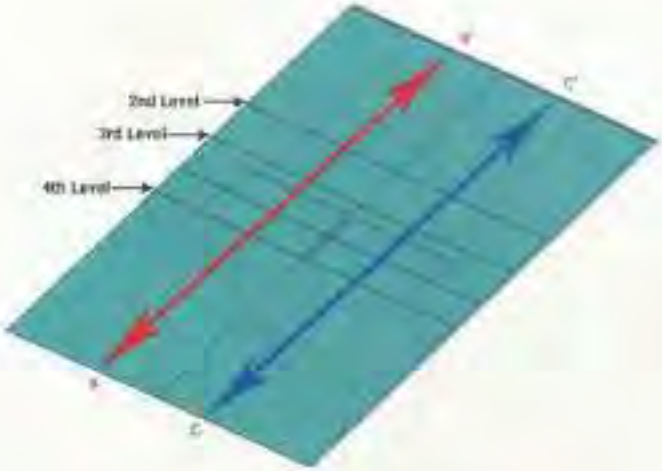


Figure 13. Paths of displacement measurements

Vertical displacement is also measured, along a path (A-A') running in contact with the hanging wall of the stope (which ultimately rests as the crown pillar) as shown in **Figure.15**.

It can be clearly seen in the Figures 14 that the displacement at the boundaries is almost nil (~0mm), thus confirming that the boundary conditions applied are correct. A maximum displacement of around 3 mm is observed on the left stope at the 3rd stage of mining. It should be noted that in major regions the displacement is positive (implying that the bending has taken place.) Also, as the mining operation proceeds (stage 1, 2 and 3) the bending increases, but once all the stopes are backfilled the positive displacement is reduced to around 2mm.

This positive displacement can be attributed to the fact that, at this mining height, the vertical stress is not much. Then, the region is acted upon by strong horizontal forces (2.0, 1.4 times the vertical stress). Now, as the mining activity proceeds and voids are created, this horizontal stress is redistributed along the roof (path A-A'), and a high horizontal stress ultimately displaces the roof upwards. Once the stopes are backfilled, this stress concentration is relaxed a bit and the displacement comes down slightly.

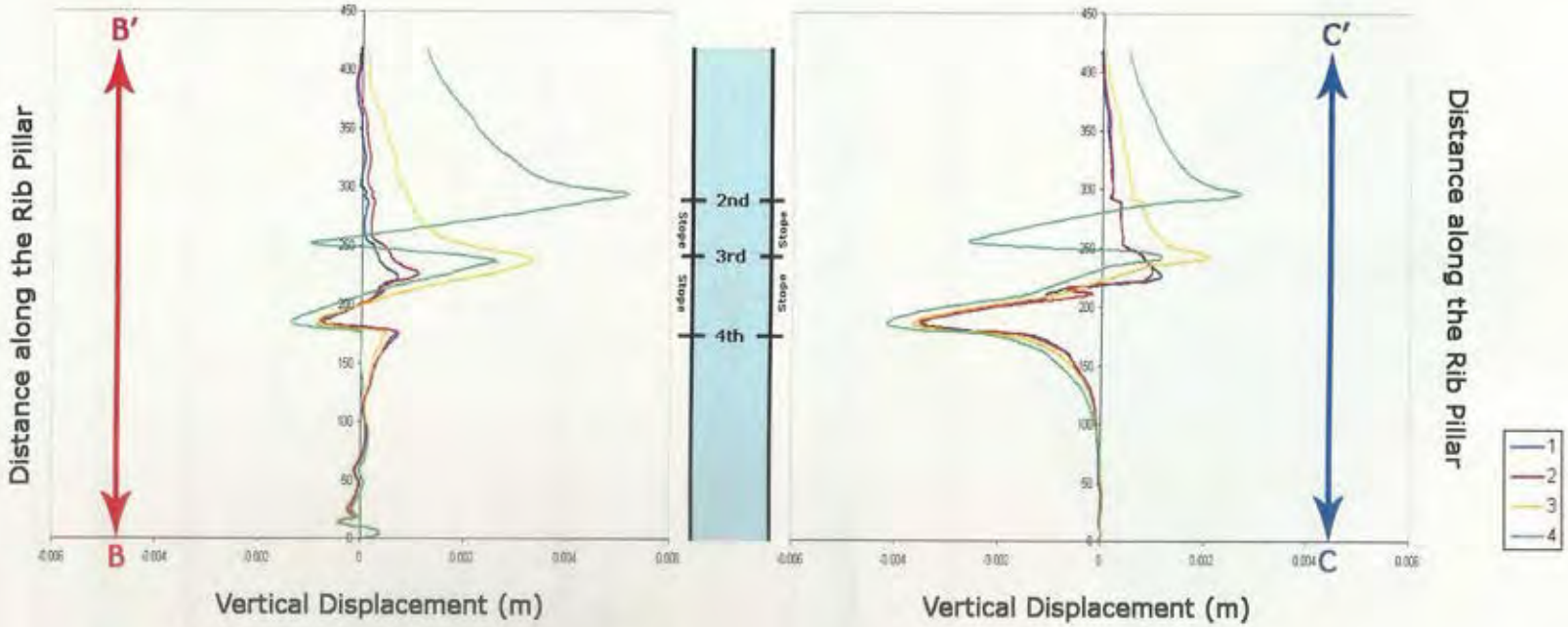


Figure 14. Vertical displacement profiles along the paths for 12 m rib pillar

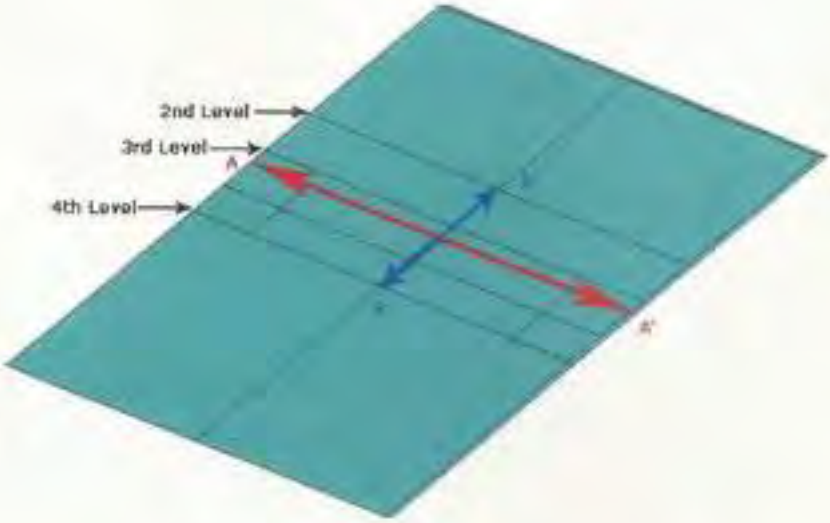


Figure 15. Paths for the measurements of safety factors

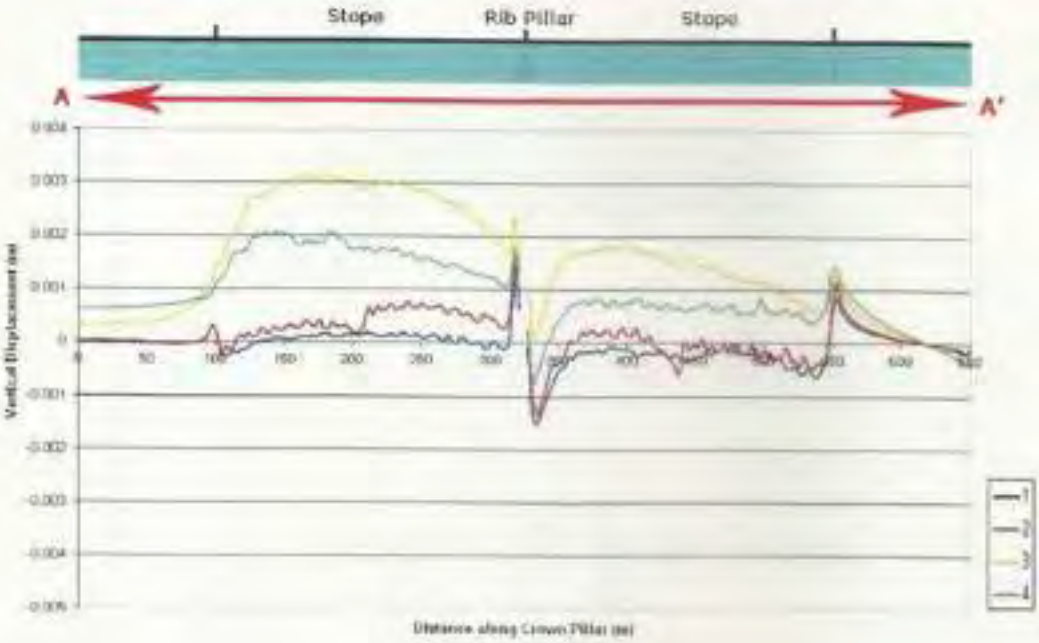


Figure 16. Vertical displacement profile along the path A-A' for 12 m rib pillar.

3.6.4 Subsidence and Horizontal Strain on the surface above Khundungri Lode

Surface subsidence or vertical movement and horizontal strain in percentage of the surface along X-X' line (**Figure 17**) is plotted in **Figure 18**. The figure shows that a maximum subsidence of 2 mm is expected when

Stage-4 stoping operation is being conducted. The subsidence value is insignificant since ore body width is narrow and filling will be done after the excavation. Due to horizontal stress, an elastic rebound is expected in the middle of the Lode 3 and main lode which may cause tensile zone on the surface. Similarly, vertical subsidence and horizontal strain along Y-Y' line is also plotted in **Figure 17**.

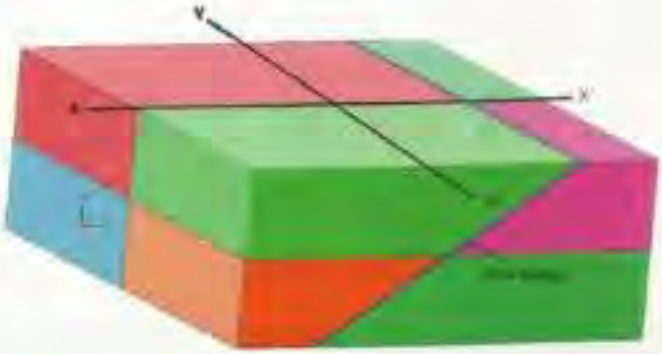


Figure 17. Paths for measuring surface subsidence and horizontal strain above Khundungri lode

Horizontal strain denotes the potential for tensile and compression zone on the surface. The maximum compressional strain is found to be 0.03 mm/m and that of tensile strain is 0.01 mm/m (**Figure 18**). The maximum vertical subsidence along Y-Y' line is found to be about 1.25 mm (**Figure 19**). The reason for this low value is mentioned before. The horizontal strain is in the range of -0.02 to 0.03 mm/m which is far less than the threshold of 10 mm/m. These data show that effect of stoping operations on the surface is minimal.

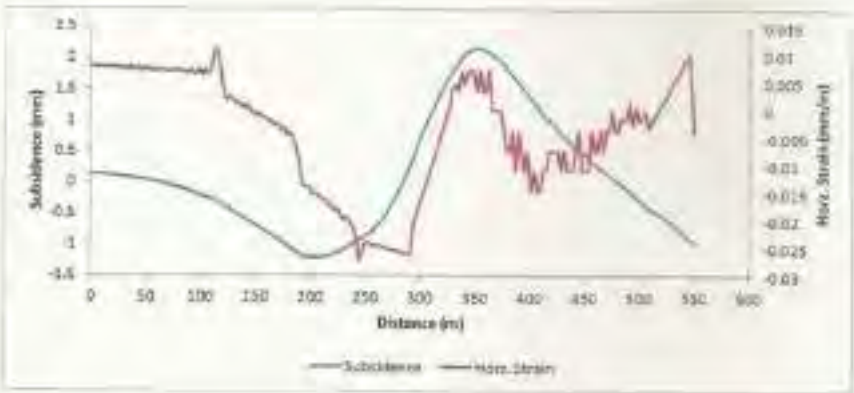


Figure 18. Vertical displacement and horizontal strain profiles along line X-X'

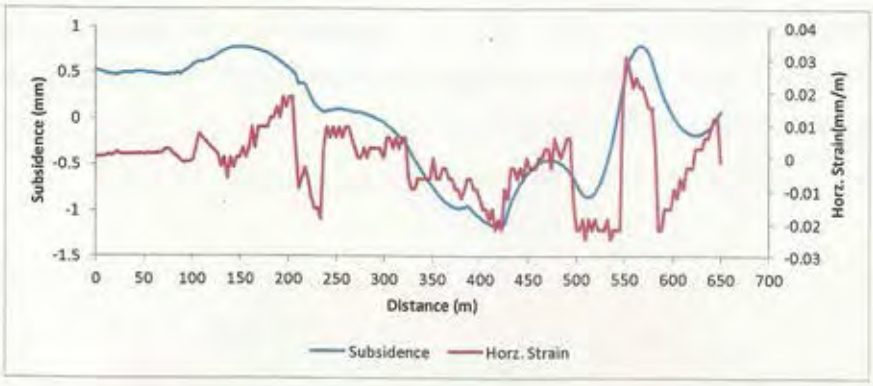


Figure 19. Vertical subsidence and Horizontal strain profiles along line Y-Y'

4. SUMMARY AND RECOMMENDATIONS

Cut-and-Fill stoping with Post Pillar method of mining has been adopted at Narwapahar mine. The main-lode ore body in Narwapahar mine above 5th level (-60 mRL) is being extracted using cut-and-fill method of stoping with post pillars. This study focuses on the determining surface subsidence at Narwapahar mine while stoping operation is conducted from 7th level (- 155 mRL) to 5th level (- 60 mRL) Spatially, the ore body is irregular in shape having variable thickness ranging between 5 m and 40 m. The strike length of the ore body is around 750 m at 6th level in Lode No. 3, the ore body has a strike length of about 350 m and has a dip of about 39° and is being extracted concurrently with the main lode. It extends vertically from 6th level to 2nd levels. Stopes from 3rd level to 2nd level have already been extracted and filled. The horizontal width of the ore body varies from 10 m to about 12 m. The minimum true thickness of the parting between main lode and Lode No. 3 is around 16 m and it is occurring in between level 6th and level 7th. Above 6th level, both lode diverge from each other.

Altogether, a total of 10 numbers of boreholes of diameter 36 mm and length of approximately 15 m, at various specified locations in 6th level of the main-lode ore body were drilled by the Uranium Corporation of India Ltd. (UCIL), using diamond drilling technique. These rock cores were transported to the Dept. of Mining Engineering, IIT-Kharagpur. RQD and recovery factor of the cores were estimated at every coring locations of the drill hole sample point. The material properties of the rocks used in the models were determined at the rock mechanics laboratory of the Mining Engineering Dept., IIT Kharagpur. Rock-joint survey was conducted at 5th and 6th levels and geological strength index (GSI) of rock mass was determined at various locations on the exposed roof and sides of the levels.

Two-dimensional (2-D) finite element modelling (FEM) techniques had been applied for designing the dimensions of the 'cut-and-fill stopes', size of the 'post pillars' and 'width of crown/ sill pillars' of main lode ore body at the Narwapahar mine of UCIL. A two-dimensional section of the widest part of the ore body, the most representative ones of the stope (resembling W16 area), is chosen for the study. Along this section, altogether 3 models were developed, viz. one insitu model and 2 models at two different mining stages. These models were considered for 'post pillar size of 5 m x 5 m at a room width of 8 m. The said section was considered for the analysis of stability of cut and fill stoping area, post pillars and crown/ sill pillars. The following conclusions and recommendations are drawn from this study of surface subsidence:

1) As mentioned earlier, cut-and-fill stope with post pillars have been analyzed using finite element method (FEM). From this study, the vertical displacement profiles after stage-2 mining sequence (during last slice of stope advancing from 7th to 6th level and completed stope between 4th and 3rd level) depict that a maximum of 10 mm displacement can occur around the stoping area which reduces to 2 ~ 5 mm over the post pillars. This signifies that post pillars are absolutely necessary to protect the roof from excessive sagging. The main reason for this magnitude of displacement is due to yielding of roof rocks and high horizontal stress. However, vertical displacement can be reduced significantly if rock bolting is practiced properly.

2) The maximum surface subsidence due to stoping operation at Narwapahar mine (up to 7th Level) would be 10 mm with a similar elastic rebound. In this study, simultaneous operation of lode 3 and main lode is assumed. The data show that subsidence potential is minimal since cut-and-fill operation with post pillar method is being practiced in these lodes.

3) The maximum horizontal strain in compression and tension are found to be 0.12 mm/m and 0.02 mm/m which are far below the threshold of 10 mm/m. Hence, the proposed method of mining i.e. cut-and-fill with post pillar is safe method as far as surface subsidence potential is concerned.

4) The maximum surface subsidence due to stoping operation over Khundungri lode would be 2 to 3 mm with a similar elastic rebound. The width of the lode is too narrow to cause any substantial impact on the ground. Again, the data show that subsidence potential is minimal since cut-and-fill operation with post pillar method is being practiced in these lodes.

5) The maximum horizontal strain in compression and tension over Khundungri lode are found to be 0.03 mm/m and 0.01 mm/m which are far below the threshold of 10 mm/m. Hence, the proposed method of mining i.e. cut-and-fill with post pillar is safe method as far as surface subsidence potential is concerned.

Finally, it may be noted that this study is not conducted to analyze the effect of a particular joint plane or shear zone on the stability of the stopes, rather it provides an overall study of stress conditions and stability assessment of the stoping area. In addition, this study does not consider the dynamic loading conditions that may occur due to blasting.

Further, it is recommended that the mine management must be vigilant for any particular weak zone, fractured zone or disturbed zone, in the stoping area, and take necessary precautionary measures to improve the ground conditions towards safe mining practices.

Prof. (Dr.) Debasis Deb,
Principal Investigator

Department of Mining Engineering,
IIT, Kharagpur – 721 302

April, 2015

Dr. Debasis Deb
Professor
Dept. of Mining Engineering
Indian Institute of Technology
Kharagpur-721302, India