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Prediction of subsidence for the chromite mine using numerical modelling techniques

A chromite orebody of Sukinda valley is planned to be extracted with sub-level open stoping method. The chromite orebody of 20 m thick, 290 m strike length and 200 m depth is developed with five stopes of equal size i.e 48.5 m × 20 m and the rib pillars size is 10 m × 20 m considering level interval 50m.

This paper describes the method for predicting the subsidence profile for the proposed mining method before commencement of the mining operation with the help of finite element method. The predicted subsidence profile is very much essential in getting the environmental clearance from the government agencies to commence the mining operation. For the prediction of subsidence for the proposed sub-level open stoping method, two dimensional numerical modelling techniques have been adopted to estimate the stress and displacement distributions on the ground surface, around the stope and rib pillar of in situ and excavation models.

Keywords: *Orebody, crown pillar, rib pillar, subsidence and finite element model.*

1. Introduction

Subsidence is a downward movement of ground surface or cavity formation at the surface due to underground workings. There are many techniques and formulas available for determination of the mine subsidence [1-3]. In this study, two dimensional finite element method has been adopted for subsidence prediction for the chromite deposit located in the state of Odisha. This subsidence prediction is an essential for getting project approval. The chromite deposit extends 290m in strike length with an average width of 20 m. The top portion of the deposit is located about 30 m below the surface and extends vertically up to 200 m. The dip angle of the orebody is 10º degree with the horizontal or 80º degree with the vertical. Country rocks of chromite orebody are weathered serpentinite, serpentinite, quartzite and pyroxenite. A quartzite hill exists on the surface towards the dip side of the orebody. The bottom most RL of the surface is 210 mRL as shown in Figs.1 and 2 [4].

The virgin chromite body (Fig.3) is developed with five stopes having two levels and size of the stope is 48.5 m in length and 20 m in width. The size of the rib pillars are left between two adjacent stopes is 10 m in length and 20 m in width (Fig.4). The interval between two levels is considered as 50 m [4].

This study is conducted to predict the subsidence due to the stope operations with sub level stoping method to obtain the environmental clearance of the project. In order to perform such tasks, borehole rock samples have been tested to estimate the geo-mechanical properties of the country rocks and orebody based standards of International Society of Rock Mechanics (ISRM) and are listed in Table 1. Rock Mass Rating (RMR) and Geological Strength Index (GSI) have also been estimated for the same [5-7]. Two dimensional numerical modelling techniques have been adopted to estimate the stress and displacement distributions in and around the stope pillars and on the ground surface to predict the subsidence.

2. Finite element method

Finite element method 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 problems for analysis. 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 [8].

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 [9-11]:

$$\{F\} = [K]\{q\} \quad \text{... (1)}$$

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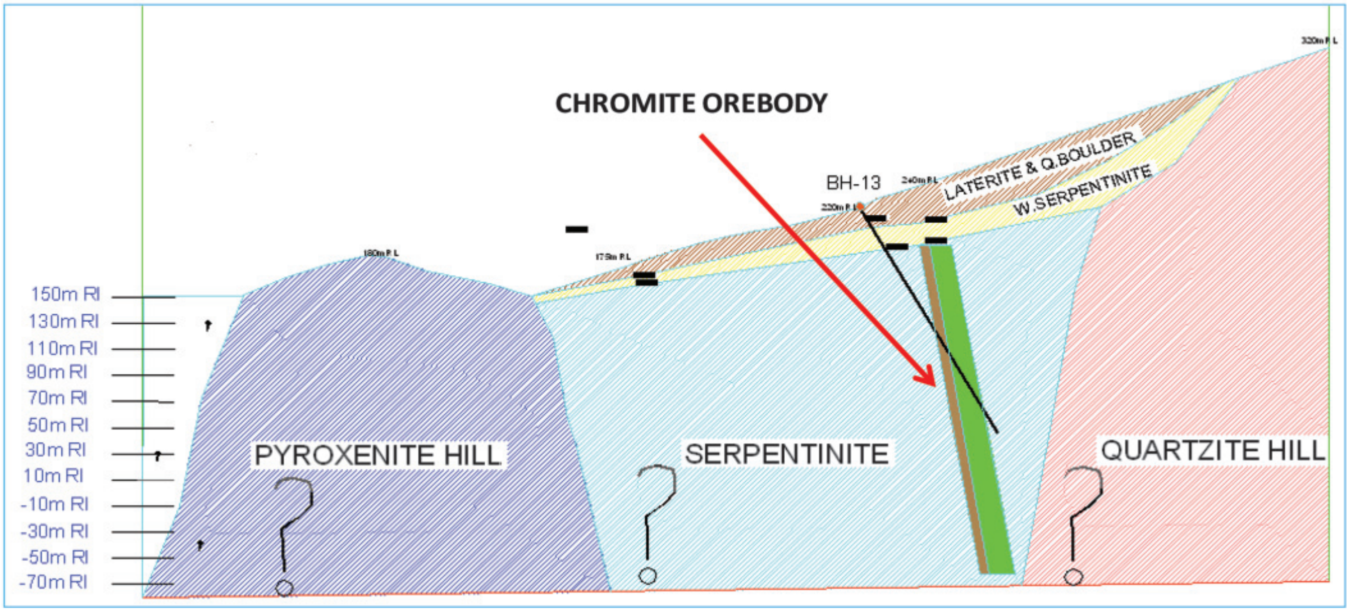
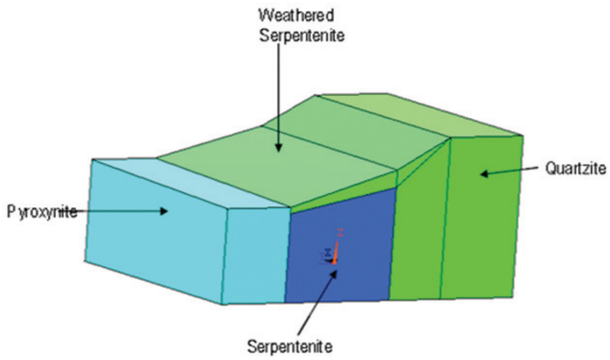
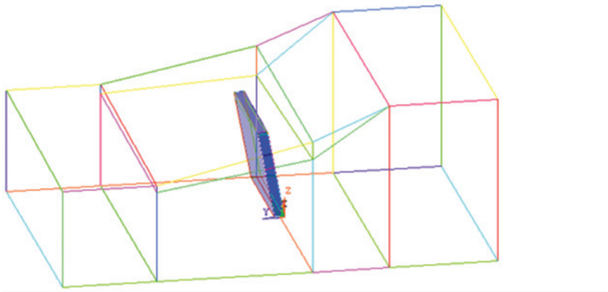


Fig.1 Orebody with the country rock



(a) Solid model showing the country rock



(b) Line diagram showing the orebody

Fig.2 Model of the study area

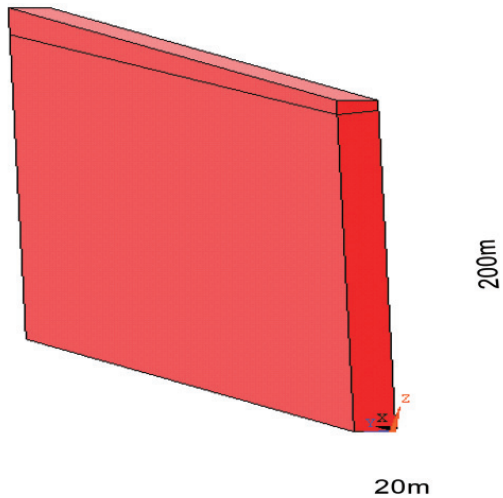


Fig.3 Chromite orebody

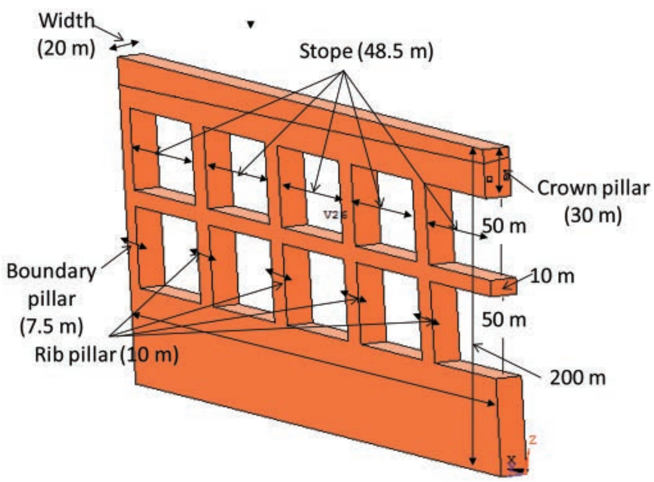


Fig.4 Extracted chromite orebody

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.

TABLE 1: MATERIAL PROPERTIES OF OREBODY AND COUNTRY ROCK

Rock type	Weathered serpentinite	Serpentinite	Chromite	Pyroxenite	Quartzite
UCS (MPa)	132	152.56	113.18	115	110
σ_t(MPa)	4.05	11.82	10.33	3.2	3.5
ρ(kg/m^3)	2745	2745	3537.9	2350	3000
$E(GPa)$	1.84	4.064	6.816	5.09	1.718
v	0.138	0.138	0.144	0.15	0.2

TABLE 2: ROCK MASS PROPERTIES USED IN THE FINITE ELEMENT MODELS

Rock or material	Modulus of elasticity (MPa)	Poisson's ratio (v)	Density (kg/m^3)	Compressive strength (MPa)	Cohesion (MPa)	Friction angle (deg)	Dilation angle (deg)
Weathered serpentenite	1840.107	0.138	2745.0	11.525	3.00	35	17.5
Serpentenite	4064.160	0.138	2745.0	3.924	1.25	25	12.5
Chromite	6816.800	0.144	3537.9	3.570	1.25	20	10
Quartzite	5090.627	0.150	2350.0	17.156	4.00	40	20
Pyroxenite	1717.700	0.200	3000.0	11.939	4.18	20	10

3. Two dimensional model of sub-level stoping method

Two 2D-finite element models have been developed to analyze the stress and displacement distribution in and around the stope pillars and also have been estimated the deformation on the ground surface or plastic zone around the stope and rib pillars. The primary motivation of analyzing in 2D is to determine the failure zone in the roof of the stope and the deformation over the stope. All 2D models are analysed considering Drucker-Prager materials in plane strain conditions. It means that rock mass is allowed to yield based on its strength and the developed plastic strain intensity has been observed around the excavations [4,9,10].

The 2D models are described as follows:

1. In situ model comprises host rock and orebody.
2. Excavation model comprises host rock, orebody, stope and the rib pillars.

3.1 IN SITU MODEL

The longititudinal section along the strike of the orebody of Fig.2 has been taken for the detail analysis of stress and displacement and also to predict the subsidence profile. This longititudinal section consists of serpentenite, weathered serpentenite and chromite orebody (Fig.5) [4].

3.2 EXCAVATION MODEL

The longititudinal section along the strike of the orebody of Fig.4 has been taken for this analysis. The excavation model consists of serpentenite, weathered serpentenite and developed chromite orebody as shown in Fig.6.

Five stopes of 48.5 m in length and 20 m in width considering 50 m of level interval have been extracted in two levels. Four rib pillars of width 10 m each are left in between the two adjacent stopes (Fig.6). The thickness of crown pillar has been considered as 30 m and the crown pillar of 10 m left between two levels [4].

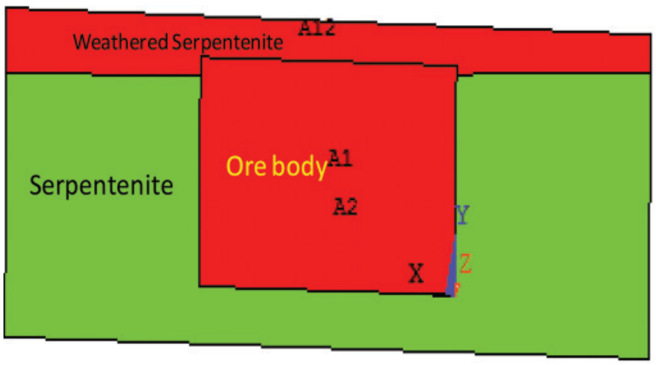


Fig.5 In situ finite element model

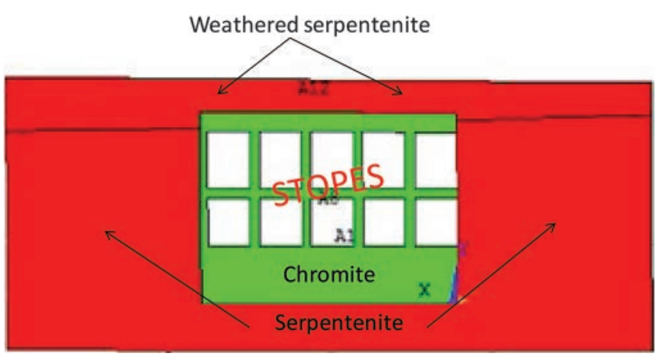


Fig.6 Excavation finite element model

3.3 MATERIAL PROPERTIES

In tact rock properties of the country rock and orebody have been estimated in the laboratory and further reduced to simulate more jointed rock mass conditions. Table 2 lists the rock mass properties those are assigned to finite element modelling for all 2D models. It can be easily seen that compressive strength of rock mass of each rock type is considered at the lower side to incorporate jointed rock mass with few centimetre spacing, weathered and watery conditions [4,6].

3.4 Finite element meshed models

The meshing of the excavation model produced an average of around 4,175 6-noded triangular elements and around 8,715 nodes. Little variations are noted in node counts with in situ model geometries. The finer mesh is developed around the stope area 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) (Fig.7) [4,6].

3.5 Loading and boundary conditions

The finite element models are constrained from two sides, those are (i) along the strike of orebody (ii) bottom surface as shown in Fig.8. The other side of the model (along the strike of orebody) is applied, the horizontal stress is equivalent to $\sigma_H = \sigma_v$, where σ_v is vertical stress in MPa. Gravity loading is also assumed for vertical direction (Fig.8) [4,6].

4. Results and discussions

All 2D finite element models have been analyzed using elasto-plastic behaviour of rock materials in plain strain condition. Results are described in terms of principal stresses and dispacement distributions in the stope pillars, crown pillars and at the surface [4].

4.1 Major principal stress (σ) distribution

The major principal stress distribution around the stope is shown in Fig.10. It is found that high stress concentration occurs at the corners of the stope. The peak major principal stress may range in between 3.15 MPa and 29.1 MPa. Tensile stress may develop in the hanging wall and foot wall rock mass.

4.2 Minor principal stress (σ) distribution

Distribution of minor principal stresses around the area is plotted in Fig.11. Tensile stress develops in the hanging wall and foot wall rock mass. Tensile stress ranges in between less than 1.0 MPa and 2.0 MPa depending on the location.

4.3 Displacement distribution

Vertical displacement profiles are calculated along the path considered at surface of the orebody, roof of the stope and across the stope as shown in Fig.9. The displacement data of in-situ and excavation models are collected for all the paths shown in Fig.9. The displacement data of insitu model is subtracted from the excavation models for the same paths. This is the resultant displacement caused due to the mining activities only. The following equation is used to determine the vertical displacement due to mining operation.

$$d = d_{excavation} - y_{insitu} \qquad \text{... (2)}$$

where, is vertical displacement due to mining operation, $d_{excavation}$ *and* – d_{insitu} are the deformation in the excavation and in situ models respectively.

Vertical displacement profiles are obtained using equation 2 along the paths B-B' and C-C' sections of the stope (Fig.12).

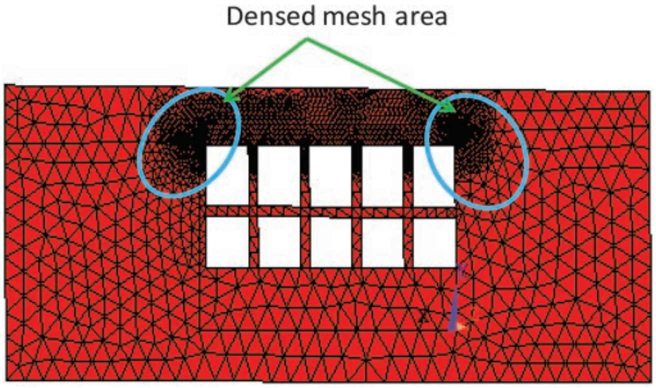


Fig.7 Finite element meshed model

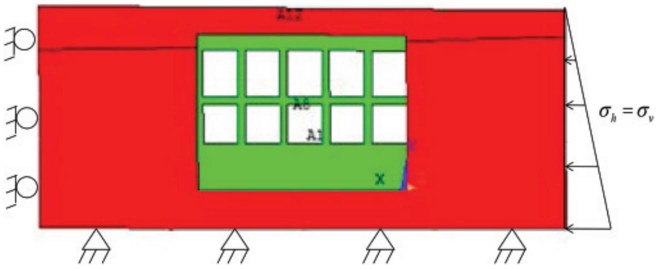


Fig.8 Boundary conditions of the finite element model

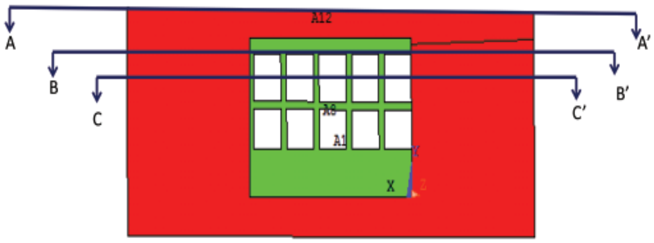


Fig.9 Profile paths considered for the determination of displacements

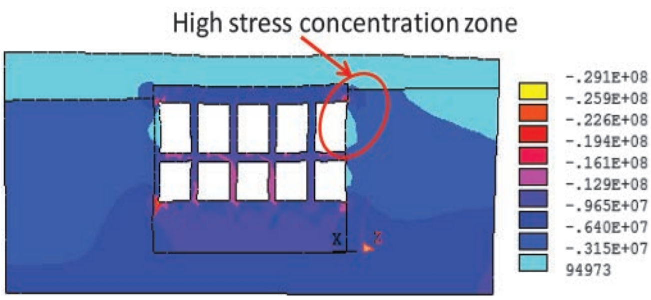


Fig.10 Major principal stresses distribution

The maximum possible displacement of 11.17 mm may occur in the roof of stope during the stoping operation at 160 mRL. Displacement may occur in the range of 11.17 mm to 6.5 mm in the roof of stope during stoping operation along the B-B' path.

The maximum possible displacement of 5.07 mm may occur in the rib pillar during the stoping operation at 125 mRL along the path C-C'. The gap in the Fig.12 represents stoping area.

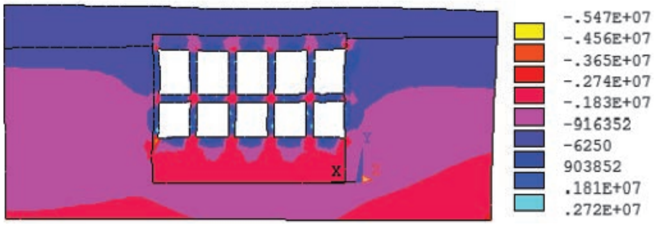


Fig.11 Minor principal stresses distribution

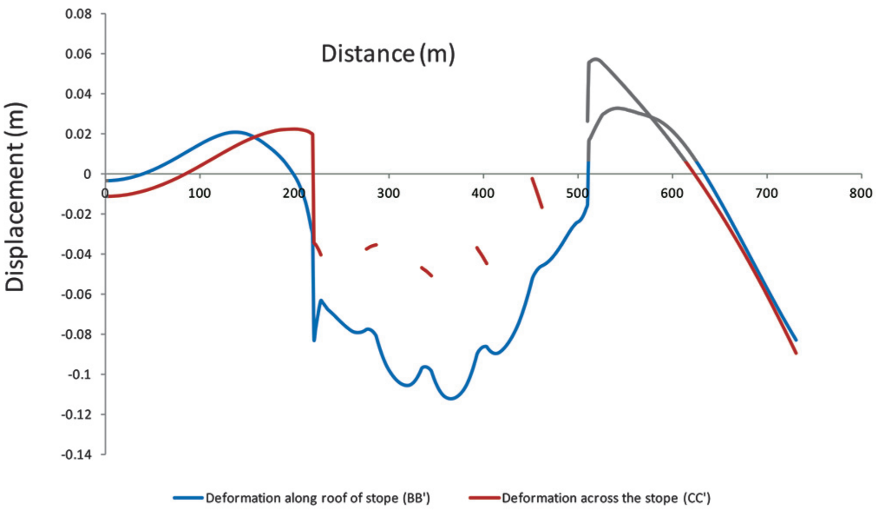


Fig.12 Vertical displacement profile along B-B' and C-C' section

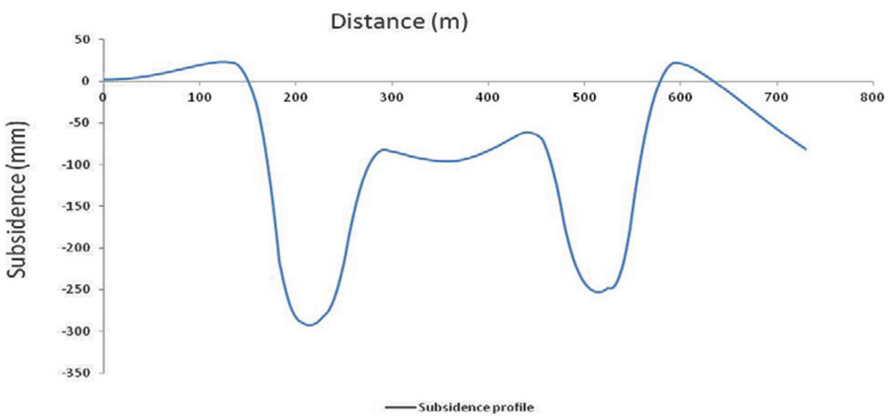


Fig.13 Subsidence profile

4.4 Subsidence profile

Vertical displacement or subsidence profile is estimated using equation 2 on the ground surface (along the path A-A'). The vertical displacement profile on the ground surface is also called as subsidence. The maximum possible subsidence of 290 mm may occur on the ground surface due to the proposed sublevel stoping operation.

5. Conclusions

The virgin chromite body of 250 m in strike length, 20 m in width and extends vertical up to 200 m is proposed to be extracted with sub-level stoping method in two levels considering 50 m as level interval. The stope dimensions are 48.5 m × 20 m and thickness of the crown pillar is 30 m.

The maximum vertical displacement at the bottom of the 30 m thick crown pillar (at 160 mRL) may go up to 11.17 mm. Average vertical displacement may occur in the range of 7.82 mm to 2.45 mm in the roof of stope during stoping operation. The maximum vertical displacement in the rib pillar (at 125 mRL) may go up to 5.07 mm.

The maximum major principal stress of 29.1 MPa may occur in the rib pillars. The compressive major principal stress occurs at the crown pillars with a range between 6.4 and 16.1 MPa. A positive value of minor pricipal stress confirms the tensile stress in the rock mass and if this value exceeds the tensile strength of the rock mass, it can be assumed that tensile failure/yielding occurs. Tensile stress of 0.9 ~ 1.81 MPa develops at the roof of the stope (in crown pillar) and tensile stress of about 2.72 MPa has developed at the rib pillars.

The maximum subsidence (vertical displacement) of 290 mm may occur in the surface (at 217 mRL) due to proposed stoping operation with sublevel method.

References

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