

Support Design during Depillaring Operation in Bord and Pillar Panel Using Numerical Simulation Method

Rizwan Hasim, Ashok Jaiswal, B.K Shrivastva

Department of Mining Engineering , IIT BHU, Varanasi, India (riz.itbhu@gmail.com)

Abstract

In an underground coal mine, most successful and economical approach to support the underground structure is roof bolting technology. The most preferred method of working in Indian coal mine is Bord and Pillar. It has been observed from the past histories that, the maximum number of accidents happens during depillaring operation. In this paper, the primary focus is to understand and analyze the roof behavior with roof bolting system in underground coal mine using numerical simulation approach. A three-dimensional (3D) model of the depillaring panel with support design using roof bolt technology is complicated to simulate. Therefore, the simulation is done near the goaf edge, where maximum chances of roof failure have been observed. On another word, it can say that simulation is done before the main fall. An elasto – plastic model has been taken for study considering physico – mechanical properties, geo - mining condition, roof bolt and grout properties as an input parameter. A case of a depillaring panel of underground coal mine has been chosen for study. The result is observed regarding axial load exerted on the bolt during mine operation. Instrumented rock bolt data has been taken for validation of the model from field observation. It has been observed in the model that maximum axial load developed on the bolt is very close to the field observation.

Key words

Bord and Pillar, depillaring panel, elasto – plastic model, three – dimensional numerical Simulation, full column grout rock bolts, instrumented rock bolt.

1. Introduction

Presently, the trend of Indian underground coal mine is going into mechanization using continuous miner technology in Bord and Pillar working. The machine has operated in wider

gallery size up to 6.6 m due to the smooth maneuvering of the machine and fast retreating during depillaring stage. In the conventional method of mining LHD/SDL machine has been used to operate the gallery size up to 4.8 m. The present practices on support design considering two major parameters such as Rock Mass Rating (RMR) and gallery size and it has been designed for conventional mining method. RMR has given by many researchers named as (Terzagi [1], Bieciawski [2], [3] and Barton et al. [4]).

The empirical design has been developed by A. Kushwaha et al. [5] during depillaring operation. In this design methodology, a generalized empirical equation has been developed to estimating the required support load density at different places of the face based on geo - technical parameters of the mine and physico – mechanical properties of the immediate roof rocks during mechanized coal pillar mining. The equation depends on various parameters such as RMR, Depth, gallery width and stress ratio. The elastic model has been used to estimate the rock load height using numerical simulation approach. The minimum and maximum principal stress σ_{1i} , σ_{3i} around an excavation are computed, the rock load height can be estimated by safety factor at different points and drawing its contour. In this method, a factor of safety taken as ≤ 1.5 .

There are two types of the support system are used in underground Bord and Pillar mining named as active and passive. Cog, chock, props are falling into the category of active support while rock bolt is a passive type, utilizing the rock strength by applying internal reinforcing stresses.

Numerous efforts were made to develop better support systems and to improve rock stability in underground working. However, for centuries, all support systems were passive and external. Since, the first use of new support technology as, slot-and-wedge rock bolts in 1927 of US metal mine (Bolstad et al., 1983) [6]. In 1943, Weigel [7], proposed the basic concept of roof bolting as a systematic support design for a weak roof. U.S Bureau of Mines (USBM) has use of roof bolting technology in 1947, to reduce the number of fall in underground working. Realizing, its importance more than 200 mines in the US, deployed new roof support in less than two years.

Rock bolting is more economical than other support system uses in underground mine because its installation is very easy as compared to the other. So, it saves material and manpower consumption to improve the productivity of the mine. It also reduces the hindrance, for the smooth operation of machinery and manpower in the underground working as compared to other support system used in mine.

Many research has been done in support design in the form of mathematical and empirical and numerical approach. The three - dimensional numerical simulation gives the reasonable understanding to analyze the complex roof strata and bolt interaction. The numerical model

indicates that the roof bolts can significantly affect the vertical stress distribution in the bolted area. So, the development of the 3D roof bolt model can benefit the studies on bolt/rock interaction substantially [8].

In this study, an attempt has been made to analyze the roof bolting system under depillaring operation by a numerical simulation method. Axial load on the bolt and roof behavior has been analyzed and understand.

2. Numerical Modeling

2.1 Methodology

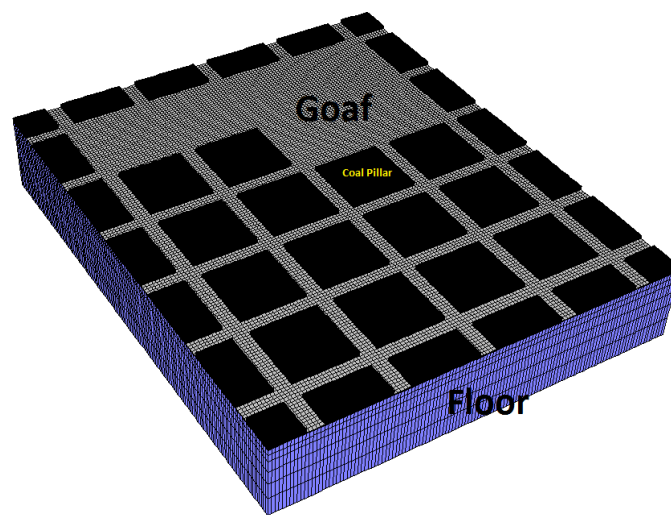


Fig. 1. Three-dimensional Views of the Panel

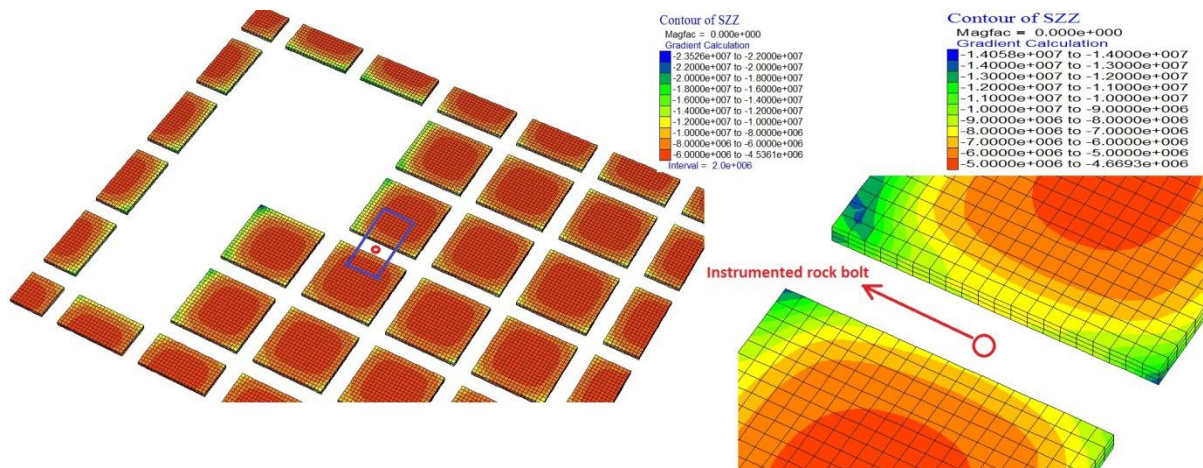


Fig. 2. Plan View of Panel Near Goaf Edge and Maximum Induce Stress Value

It has been observed by field observation and numerical simulation that the induced stress on the pillar increases with the advancement of goaf [9]. In the case of depillaring operation, three – dimensional simulation of the whole panel with rock bolting is complicated because it has taken

more computational time to solve. So, to overcome such problem, an analogy has been developed to replicate three-dimensional depillaring panel into a three-dimension section of the panel. The three – dimension sectional view of the panel is shown in the Fig. 1. The plan view of the area, where the study has been carried out near goaf edge as shown in Fig. 2. Three – dimensional discretizational view of the model is shown in Fig. 3.

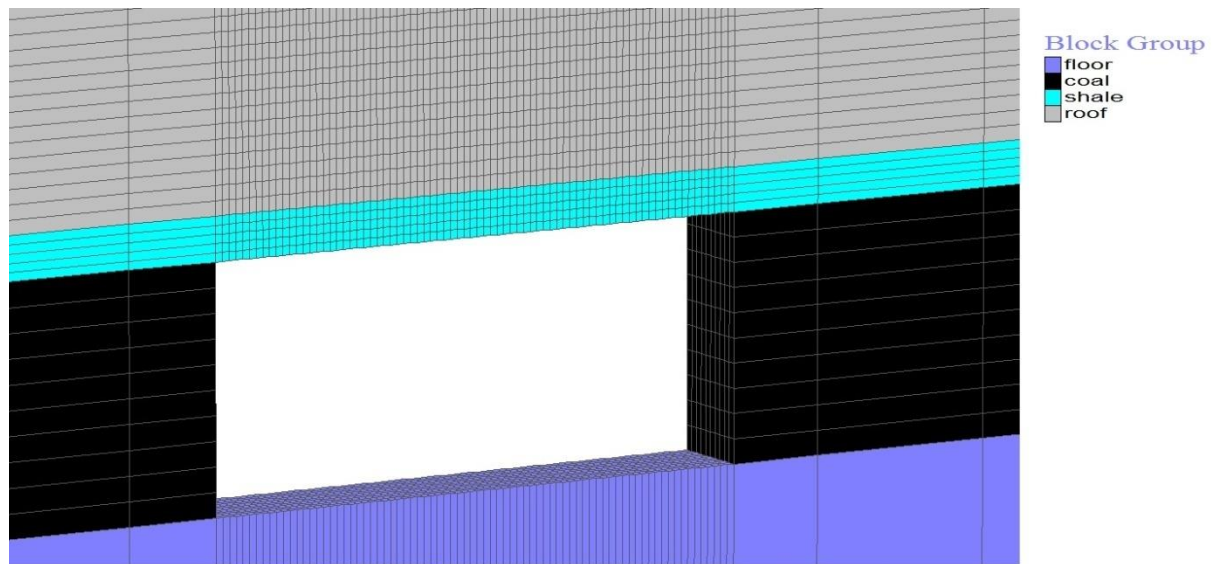


Fig. 3. 3D Sectional View of the Model

Table 1. Axial Load On Rock Bolt in Different Stages of Mining

Mining Stages	Total Stress (MPa)	Axial Load in (tonne)	
		Instrumented Rock bolt result_IRB1 (Field)	Instrumented Rock bolt result (Simulation)
Development stage		0.2	0.25
Depillaring Stage			
Stage 1	5.87	-	0.45
Stage 2	6.37	-	0.49
Stage 3	6.87	-	0.54
Stage 4	7.37	-	0.58
Stage 5 (Near Goaf edge)	7.87	0.55	0.61

It has been analyzed that the load on the model is continuously increasing with the advancement of the goaf edge and it has been observed maximum value varies from 7.0 – 8.0

MPa in three- dimensional depillaring panel model shown in Fig. 2, whereas 7.87 MPa has been calculated from the equation (1) below. In Table 1, maximum induce stress at subsequent stages of mining have shown. The width of the 3D section of the model taken into consideration is row spacing.

The maximum induce stress has also been calculated with the help of following empirical equation. (1)

$$Su = 0.025H + \frac{8.646}{10000} H \sqrt{I} \text{ MPa} \quad (1)$$

where, Su = ultimate induced stress,

I = capability index and

H = average cover depth of coal seam.

Capability, index has taken in this case = 2208 [9]

Now, the steps involved to simulate the rock bolt in three-dimension section of the panel has described below: [10]

In the first step, the model has been simulated in the development stage to evaluate the response of roof behavior and rock – bolt – grout interaction.

In the next step, the model has been simulated in the depillaring stage. The maximum induced stress applied to the three - dimensional model and analyze the response of bolt-grout-rock interface regarding axial load exerted on the model. In between, there are numbers of intermediate stages have been simulated. Mining stage one to five shown in Table 1 shows the different value of induced stress. Table 1 also shows the changed amount of the axial load in tonnes exerted on the bolt in different mining stages.

2.2 Model Geometry

The discretizational view of the model consisted four numbers of layers including floor, coal, shale (immediate roof), and main roof. The dimension of the model of a section of the panel is 62.8m in height, 26.0 m in width and 1m long shown in Fig. 3. The discretization is more in the gallery where the bolt has installed and less on the pillar because the focus is to interpret the behavior of the rock bolt interaction with grout material and rock mass in the gallery.

2.3 Boundary Condition

The height of the model is 30.0 m, and the actual depth of the cover of the coal seam is 120 m. So, the vertical stress of 2.25 MPa has applied to the model on top, which has calculated by using the equation (2) with gravity loading. The calculation involves to calculate the verticle stress is to calibrate the model with an actual dimension of the mine. The horizontal stress 2.03 Mpa can be calculated by using the equation (3). All side of the model has been fixed for simulation process.

2.4 Material Properties

The primary focus of the study is to analyze the behavior of the roof within the bolt length. An elastic property has been used for simulation process of the model except for the immediate roof. The actual behavior of the roof rock is not perfectly elastic in nature. So, the immediate roof has been taken as strain softening material for simulation in Flac – 3D.

In - situ vertical stress can be expressed as

$$\sigma_v = \rho g D \quad (2)$$

And, In - situ horizontal stress [5]

$$\sigma_h = \sigma_v \frac{\nu}{1-\nu} + \frac{\beta E G}{1-\nu} (H + 1000) \quad (3)$$

where,

σ_v = vertical stress in Mpa,

D = depth in m,

ρ = average density in t/m^3 ,

E = Young's Modulus in MPa,

σ_h = horizontal stress in Mpa,

G = is the thermal gradient $^{\circ}C/m$,

g = acceleration due to gravity in m/s^2 ,

ν = poission's ratio,

β = is the coefficient of thermal expansion in $/^{\circ}C$,

Table 2. Physico - Mechanical Properties of the Rock Strata

Rock Type	Modulus E, (MPa)	Poisson's Ratio	Density (kg/m³)	UCS MPa	Tensile Strength MPa
Shale	4000	0.41	2270	24.50	1.64
Sandstone	1000	0.31	1970	32.50	2.17
Coal	4000	0.27	1350	20.50	1.37

Table 3. Geo – technical Properties of the Numerical Model

Rock Strata	Thickness (m)	Shear Modulus (GPa)	Bulk Modulus (GPa)	Friction angle (degree)	Cohesion (MPa)
Top Layer	30	1.98	3.47	40	10.0
Coal	3.0	1.57	2.89	40	5.0
Bottom Layer	30	1.90	4.38	40	10.0

Table 4. Geo – technical Properties of Immediate Roof

Rock Strata	Friction angle (degree)	Cohesion (MPa)	Dilation angle (degree)	RMR
Roof Strata (Shale)	25	1	0	52

Table 2 shows the physico-mechanical properties of rock & coal and Table 3, 4 shows the rock, coal, properties used in the numerical model. The Sheorey failure criteria have been used to calculate the properties used in the model. [5]

After the development, there might be some yield zones formed in the roof on the entry. To cover this essential process 5.0 m rock (shale) in the immediate roof was simulated as strain-softening material considering the effect of weak planes or joints on the rock-mass strengths. The rock bolt has been considered as a linear element.

3. Site Details

In this study, Mine A has chosen which is working with Bord and Pillar method using continuous miner technology. This mine has previously developed by a conventional mining method using SDL/LHD operation of five heading panels. The pillar size is 21.2 m corner to corner and gallery width 4.8 m during development operation. Continuous miner technology has operated during the depillaring operation. Gallery size has been widening from 4.8 m to 6.5 m for smoother operation of continuous miner technology. This result in reduced the pillar size 19.5 m from actual size 21.2 m. The working seam having thickness varies from 3.0 m to 4.0 m, and the extraction height has 2.8 m - 3.0 m borehole cross section shown in Fig. 4 leaving 0.5 m of coal in the roof because of massive shale having 5 m thickness is present above the coal seam. Panel - 6 has been chosen for study, and the depth of working varies from 104 m to 120 m. Fig. 5 shows the detailed instrumented plan of the panel. Panel – 6 of mine A consists of 48 numbers of pillars, which has to be extracted in depillaring operation. Fig. 6 shows the extraction pattern of Pillar by continuous miner and support pattern in the gallery has shown in Fig. 7.

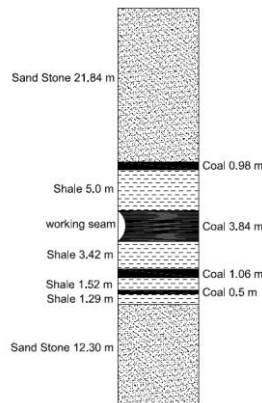


Fig. 4. Borehole Cross-section (Not to Scale)

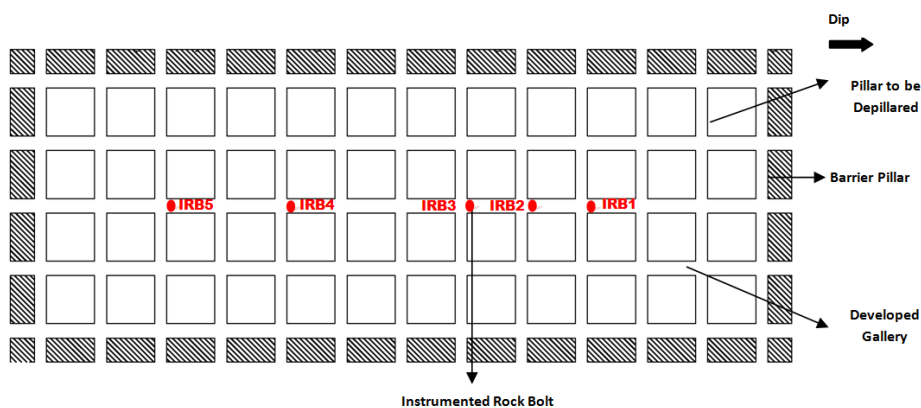


Fig. 5. Detail Instrumented Plan of Panel 6 of Mine – A

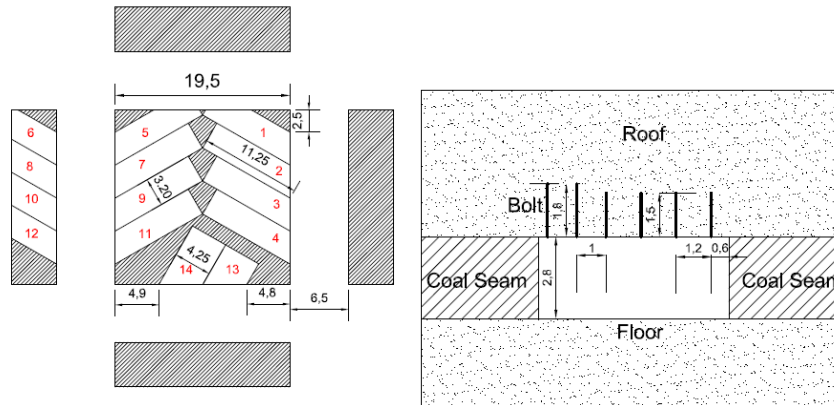


Fig. 6. Extraction Pattern of Pillar by Continuous Miner Fig. 7. Existing Support System in Gallery

4. Field Instrumentation

Instrumented rock bolt and stress meter is the monitoring device installed in the panel. This will be used to get the value of the axial load, bending moment and stresses on the pillar.

Instrumented rock bolts having 18 gauges (9 left and right side) has been installed in mine as shown in Fig. 8.

Five instrumented rock bolts named (IRB1, IRB2, IRB3, IRB4, and IRB5) of length 2.4 m were installed vertically in the immediate roof strata at five selected position of the level galleries in the panel as shown in Fig. 5.

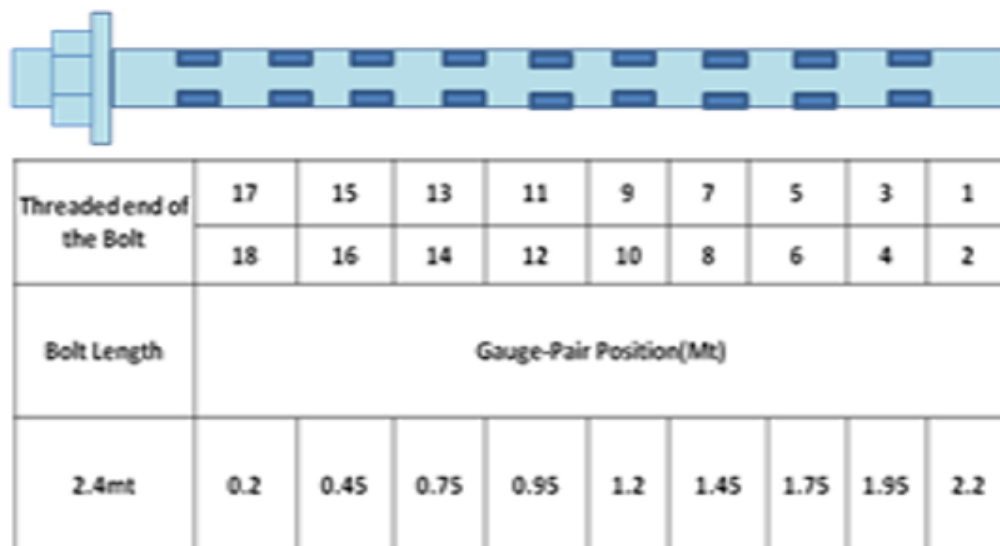


Fig. 8. Instrumented Rock Bolt

5. Field Observation

The mine has a general trend of major fall after two to three pillar is being extracted. Therefore, the installation time of the instrumented bolt, when the working face was 2 to 3 pillar away. The observation has continued till the goaf edge reached near the instrumented bolt stress has been observed with the help of stress meter installed in the pillar. The maximum load has been observed in the range of 0.25 tonne to 1.10 tonne on different instrumented bolt installed in the panel. The maximum load on each bolt was observed 1.5 m - 2.0 m from the roof level

6. Results and Discussions

Fig. 9 shows the maximum principal stress of model distribution with rock bolt in the development stage. The axial load exerted on roof bolt is shown in Fig. 10 which is 0.25 tonne.

In depillaring stage there are five numbers of the model are simulated the results have shown in Table 1 and graph are shown in Fig. 12. The maximum axial load exerted on the rock bolt is shown in the 5th stage where the induced stress is maximum shown in Fig. 11 and least value has been observed in 1st stage.

The maximum axial load in instrumented rock bolt IRB1 is 0.55 tonne has been observed from field instrumentation results, and from the model results the maximum axial load shows in the 5th stage is 0.61 tonne. Therefore it has been observed that the model has validated with the field observation.

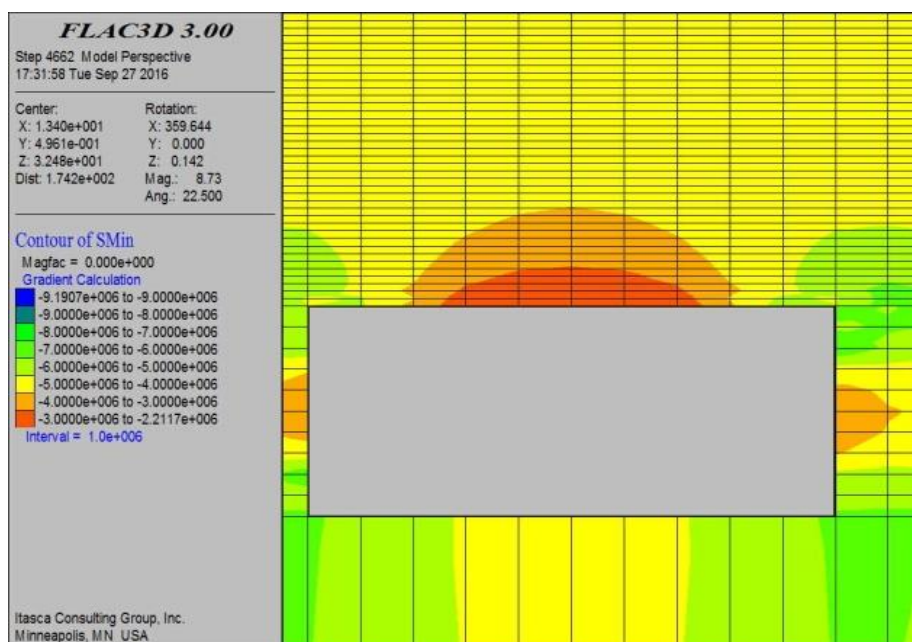


Fig. 9. Maximum Principal Stress in Development Stage with Roof Bolt

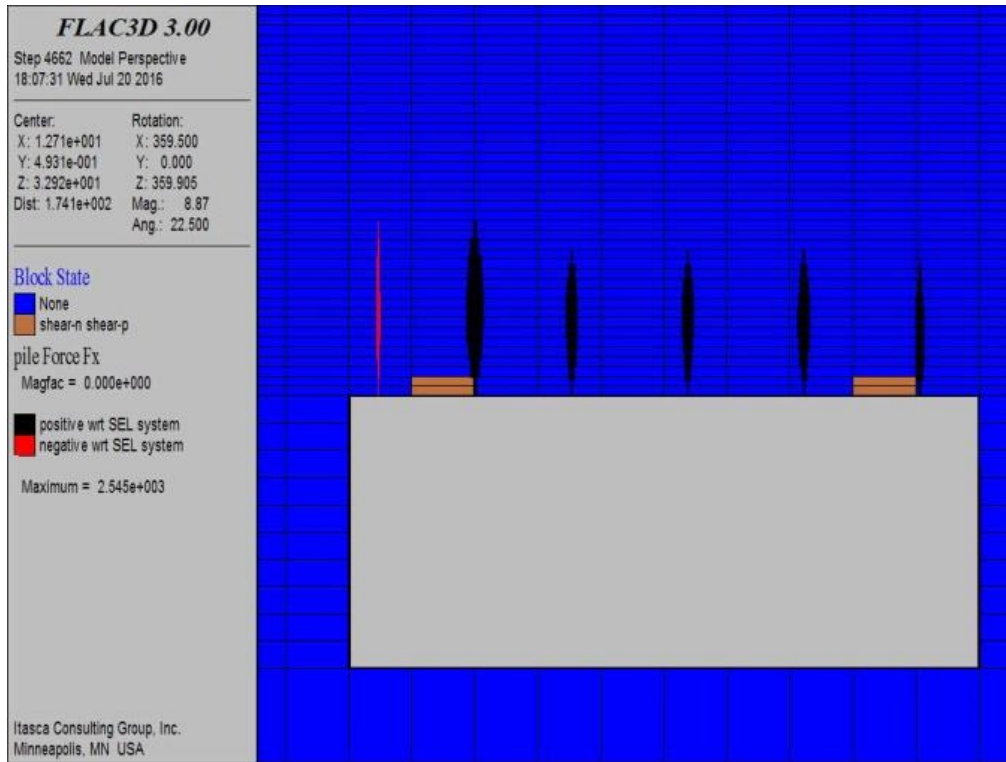


Fig. 10. Axial Load on Bolt in Development Stage

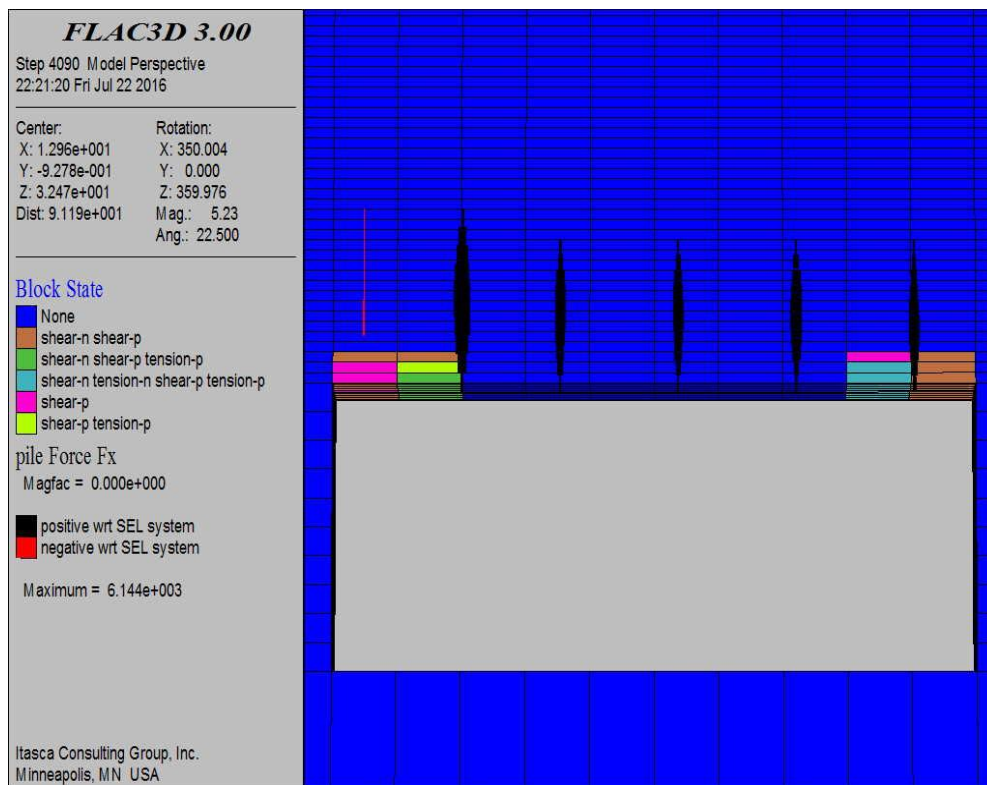


Fig. 11. Axial Load on Bolt in Depillaring Stage (5th Stage)

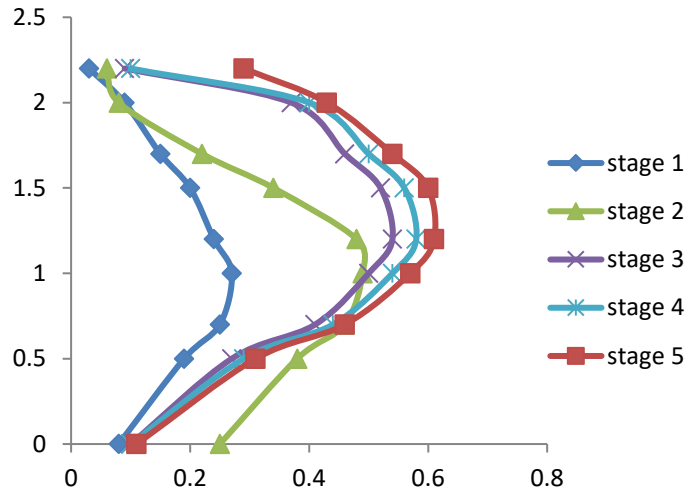


Fig. 12. Shows Axial Load in Different Depillaring Stages

Conclusion

The 3D numerical model results indicate that during development stage the axial load on rock bolt is 0.25 tonnes. In depillaring stage, it has been observed, with the advancement of goaf edge the value of induced stress and axial load occurred on the bolt increases. The maximum value of induced stress has been observed as 7.87 MPa, and axial load on the bolt is 0.61 tonne.

The similar conclusion has also obtained when comparing the axial load on roof bolts between the model-predicted and field-monitored results. In other words, the proposed three-dimensional roof bolt model has enough accuracy to simulate its behavior.

Also, it has found that the roof bolts can significantly increase the stiffness of surrounding rocks. It helps to understand that why the roof bolts can reduce the roof sag in underground entries.

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