CHAPTER 7.
PARAMETRIC STUDY

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7.1 General

Different reported studies and field observations found many responsible factors for the design of support systems in bord and pillar operation. Different key parameters for optimum support design have been chosen based on experiences from literature and information gathered from mining professionals in Indian coalfields during the field visit. A parametric study has been carried out considering the varying geo-mining conditions.

7.2 Depth of coal seam

Depth of working influences the behaviour of rock mass in and around line of extraction during depillaring operation. Generally, the high value of induced stresses occurs at a high depth of cover and during working under competent strata (Singh et al., 2011), which ultimately influences the performance of support design near the goaf edge. It has also been observed that dynamic loading is generated during the main fall at the goaf edge. This effect is considered while formulating the equation for the estimation of yield zone (RLH) and axial load exerted on the bolt for optimum design of rock bolt near goaf edge.

Thus, depth of cover is selected as one of the important factors for this study. Mechanized depillaring operation is practiced from shallow to higher depth of cover (60-377 m). Some of the field data are shown in table 7.1, and the adopted bolt design has shown mixed results. Considering the issue, four different depth of cover viz. 100 m, 200 m, 300 m, and 400 m are considered for the investigation illustrated in table 7.2.

Nomenclature of the different cases is defined in term of A, B, C and D shown in table 7.2.

Table 7.1 Different mechanized depillaring faces using CM in India

Name of mine	Geo-mining parameters of different mechanized depillaring faces						
	Depth cover (m)	**Pillar size (corner to corner) m**	**Bord width (m)**	**Height of extraction (m)**	**Overlaying strata**	**RMR**	**Cutting pattern adopted**
Pinoura (SECL)	60	18.5x19.5	6.5	3.0	Easy to moderate	42	Fish- tail
Anjan Hill (SECL)	85	28.2x28.2	6.6	4.5	Moderate to difficult	52	Split and fender
Jhanjra (ECL)	125	26.0x26.0	6.0	4.2	Moderate to difficult	58.6	Split and Fender
VK7 (SCCL)	377	40.0x40.0	6.6	4.6	Extremely difficult	62	Split and Fender
Tandsi (WCL)	260	40.0x40.0	5.5	3.0	Unstable roof strata	41	Split and Fender
GDK 11 (SCCL)	325	48.0x46.0	6.0	4.6-6.0	Difficult	47.8	Split and Fender

Table 7.2 Nomenclature of different cases used in parametric study

Depth	Gallery Width	RMR	Bolt density
100 - A	5.5 - A	40 - A	Without bolt - A
200 - B	6.0 - B	50 - B	4 m2 /bolt - B
300 - C	6.5 - C	60 - C	2.25m2 /bolt - C
400 - D			1.44 m2 /bolt - D
Total Number of cases = 144			

7.3 RMR of roof

RMR-based support design is most popularly used to estimate the proper support pattern in Indian coalfields. The mentioned empirical relationship of rock mass failure criterion discussed in Chapter 6 for Indian coalfields uses Bieniawski RMR, but CMRI-ISM RMR (Venkateshwarlu et al., 1989) is found to give reasonable results (Kushwaha et al., 2010). CMRI RMR is commonly used in Indian coalfields and is a tested parameter to characterize roof strata. Therefore, CMRI-ISM RMR (Venkateshwarlu et al., 1989) are varied to know their influence over the yield zone (RLH) for the design of support systems using roof bolt technology. RMR values varied from 40 to 60 (shown in Table 7.2) to depict Indian geo-mining conditions consisting of weak to moderately strong roof strata.

7.4 Gallery width

As illustrated in table 7.1, the mechanized working of Bord and Pillar using CM technology gallery size varies between 5.5 m to 6.6 m. A wider gallery is required for CM technology to easily maneuvering the machine during the operation. Most of the Indian mines are adopted the CM technology where the development activities are over in the panel using the conventional mining method. So, before deployment of the CM technology in the mine, the developed gallery needs to be widening for smoother operation of the machine. The high gallery width tends to chances of failure in the gallery as well as junction because of the larger span. Roof sagging is reported in some of the cases in the higher width of the gallery. So, in this study, one of the parameters is taken into consideration is the higher gallery width ranging from 5.5 m to 6.5 m shown in table 7.2.

7.5 Different combination of bolt pattern/bolt density (m^2/bolt)

The study focused on designing the optimum support pattern during depillaring operation in bord and pillar panels. The density of the bolt is one of the critical parameters is to give the appropriate support design. According to the thumb rule, a larger density of bolt will give effective support as compared to the lesser density of support. Still, at the same time, the study revealed that at some point in time, the yield zone remains constant irrespective of increasing bolt density. So, the study will give the idea of optimum support design to give the effective support design vis-á-vis to reduce the time for installing the support, which is not required.

For estimation of an appropriate number of bolts (bolt density), different models were run with different bolt patterns (bolt density) such as without bolt, 3 × 3 bolt (4 m2/bolt), 4 × 4 bolt (2.25 m2/bolt) and 5 × 5 bolt (1.44 m2/bolt). The example for variation in bolt density of 6 m wide gallery is shown in figure 7.1. The length of the rock bolt considered is 2 m in all the cases.

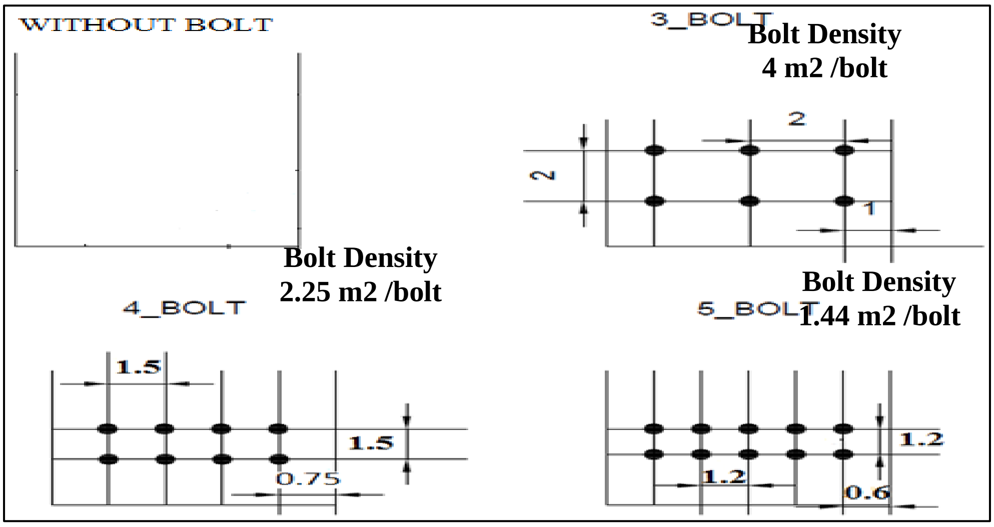


Figure 7.1 Different bolt pattern considered in parametric study

Considering all the key parameters mentioned above, a parametric study has been conducted. Following are the steps to prepare for numerical simulation analysis using FLAC^{3D}.

7.6 Model Preparation for parametric study

This section illustrates the steps to be followed for preparation of the model selected for parametric study.

7.6.1 Model Geometry

For ease of solving computational models and saving time, only four pillars with five openings have been modelled for parametric studies. The discretization has been considered fine in the corner of pillar and gallery for better results. The Discretised view of the plan at seam level has been shown in figure 7.2. The discretised view of the model has been shown in figure 7.3.

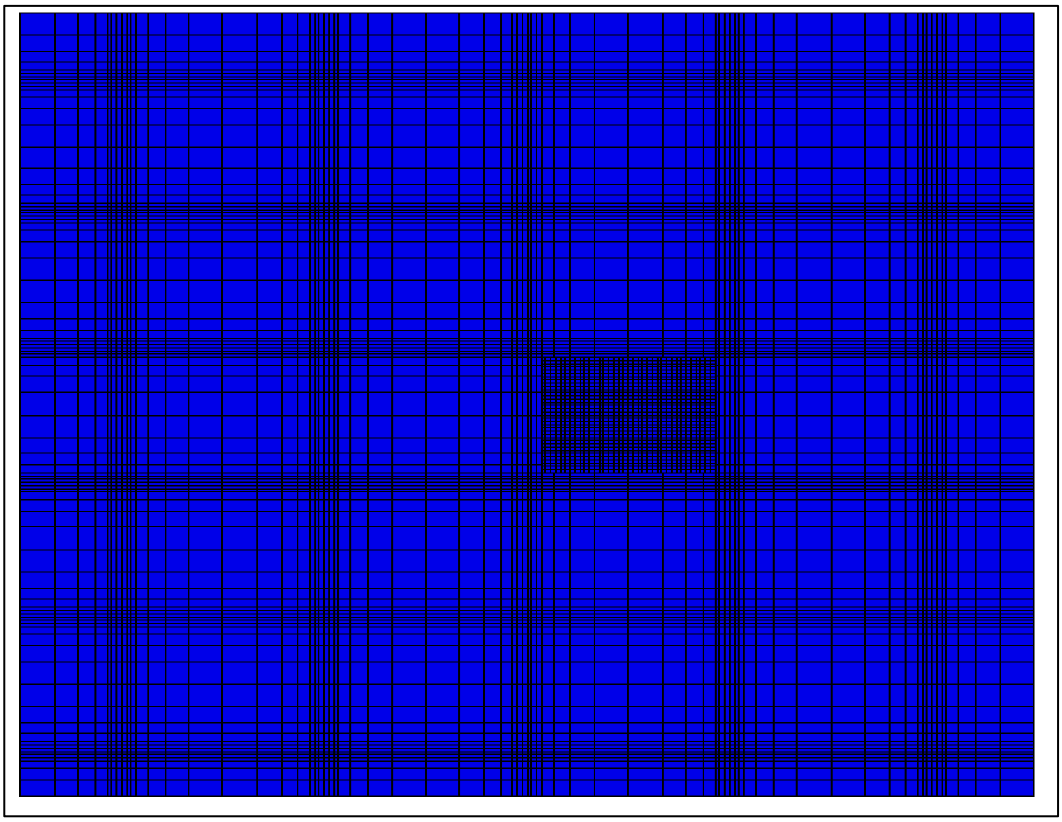


Figure 7.2 Discretised view of model

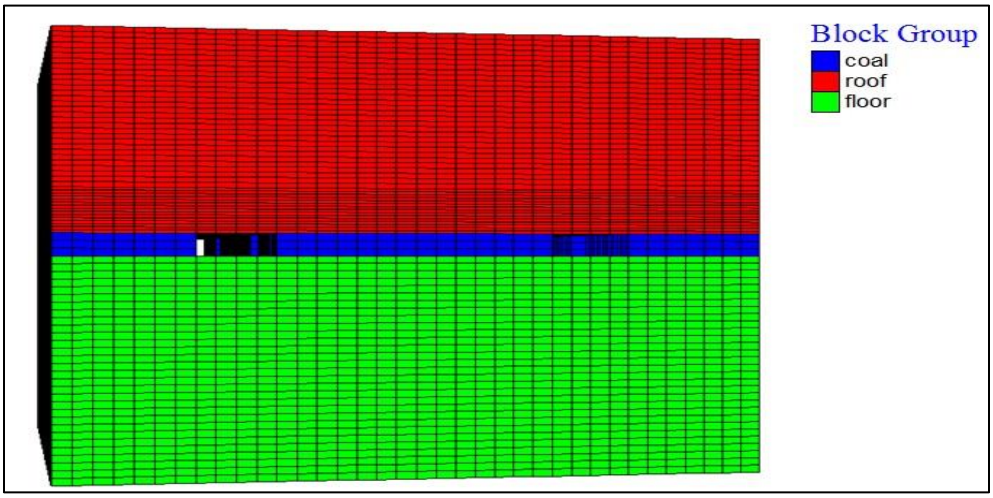


Figure 7.3 Three-Dimensional view of model

Different associated steps involving the development of gallery and extraction of pillar including installation of rock bolt of the modelling are expressed with the help of flow chart shown in figure 7.4.

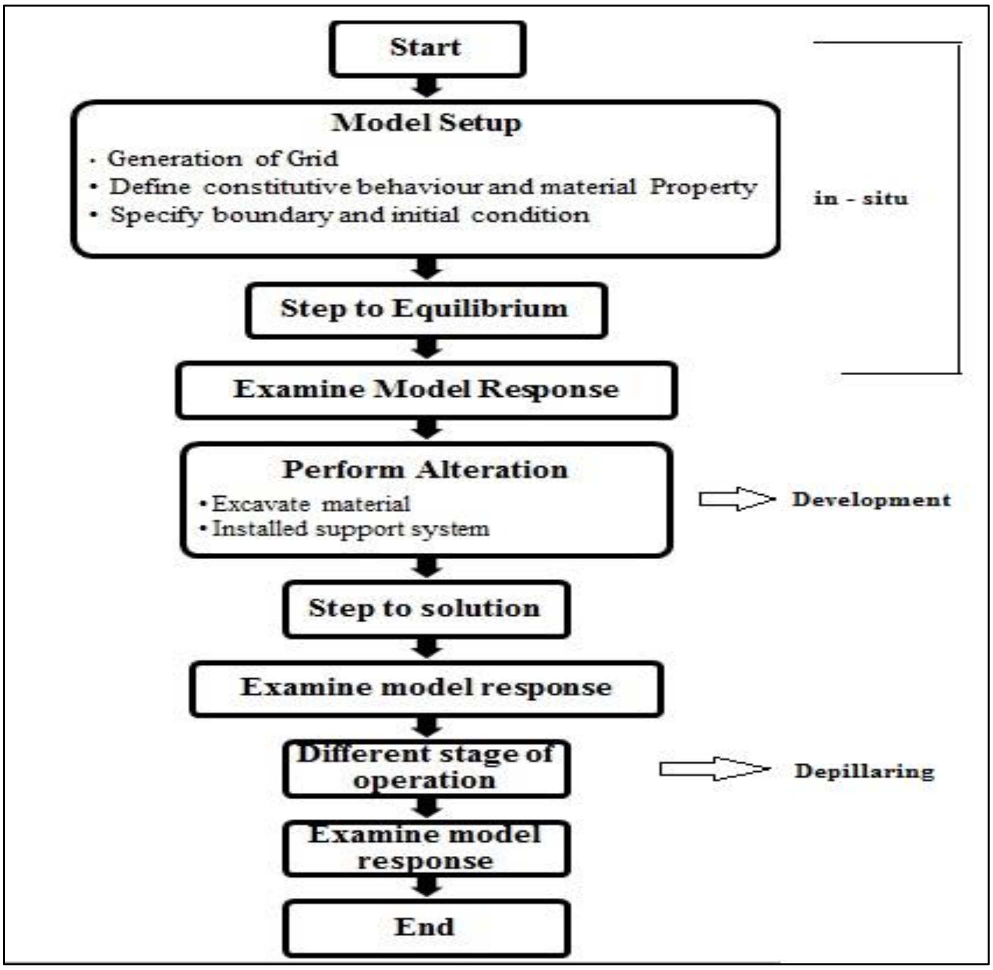


Figure 7.4 Flow chart of model adopted for simulation study

7.6.2 Selection of appropriate material behaviour model

The actual behaviour of roof and coal seam is elastoplastic behaviour. In the simulation process, the roof and floor were considered strain-softening materials. In this study, Mohr - Columb failure criteria are taken into consideration to calculate the peak value of cohesion (c) and friction angle (ϕ). The rate of reduction of residual strain in the strain-softening model can be calculated using the graph shown in figure 6.2, as discussed in Chapter 6. This will give the appropriate yield zone in the roof as well as in the pillar during the different stages of operation.

7.6.3 Material property

In this section, material properties used in the model are listed in table 7.3. Other than this, strain-softening material properties are taken based on different RMR of roof described in the previous section.

Table 7.3 Rock mass properties used in parametric study

Rock Type	Young's Modulus E, (MPa)	Poisson's Ratio	Density (kg/m3)
Sandstone	7,000	0.25	2500
Shale	5,000	0.25	2500
Coal	2,000	0.25	1350

7.6.4 In-situ stress and boundary condition

The in-situ stresses are well-known factors that influence the stability of an underground structure during mining. For the Indian Coalfield (Sheorey et al. 2001) proposed an equation for average in-situ vertical stress and horizontal stress. The details have discussed in Chapter 6.

7.6.5 Installation of rock bolt

The rock bolt installed in the model after the gallery has been developed is shown in figure 7.5. The length of the bolt is taken as 2 m. the simulation will start after the installation of the bolt in the entire panel. The properties of the rock bolt are taken into consideration in numerical modelling is illustrated in table 6.3 discussed in Chapter 6.

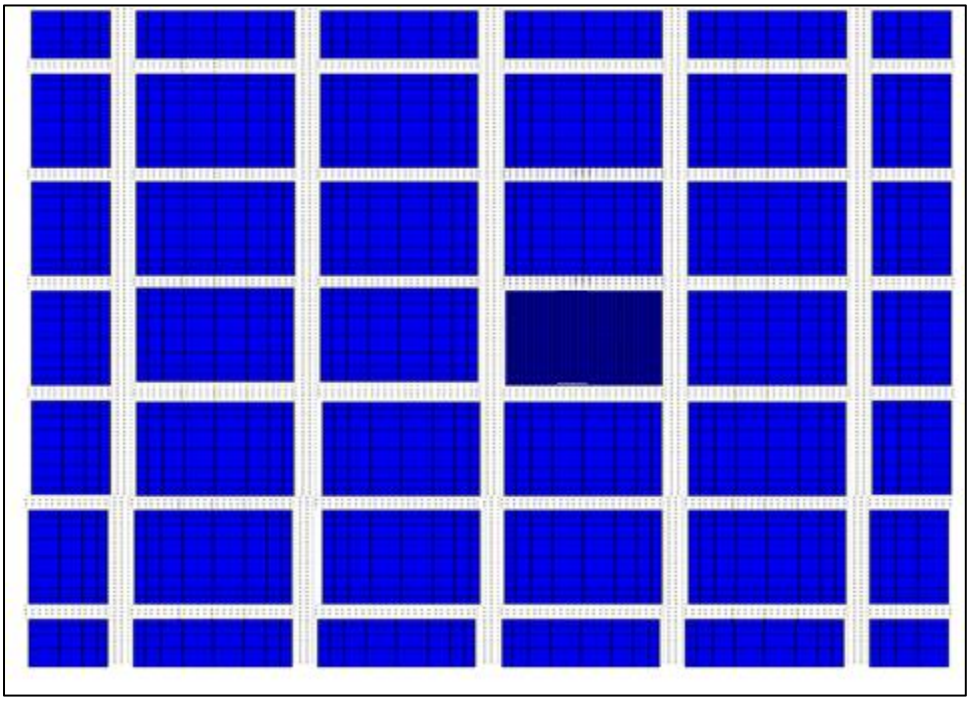


Figure 7.5 Plan view of developed panel with installed rock bolt

7.6.6 Simulation of model

This section discussed the simulation stages of different models taken into consideration in the parametric study. The steps for simulation procedures are outlined in the following sections.

7.6.7 Model simulated in in-situ condition

The model is simulated in an in-situ environment to check the model response. The model response will give information regarding the stress distribution. For varying depth parameters for different models, the stress distribution shows different results.

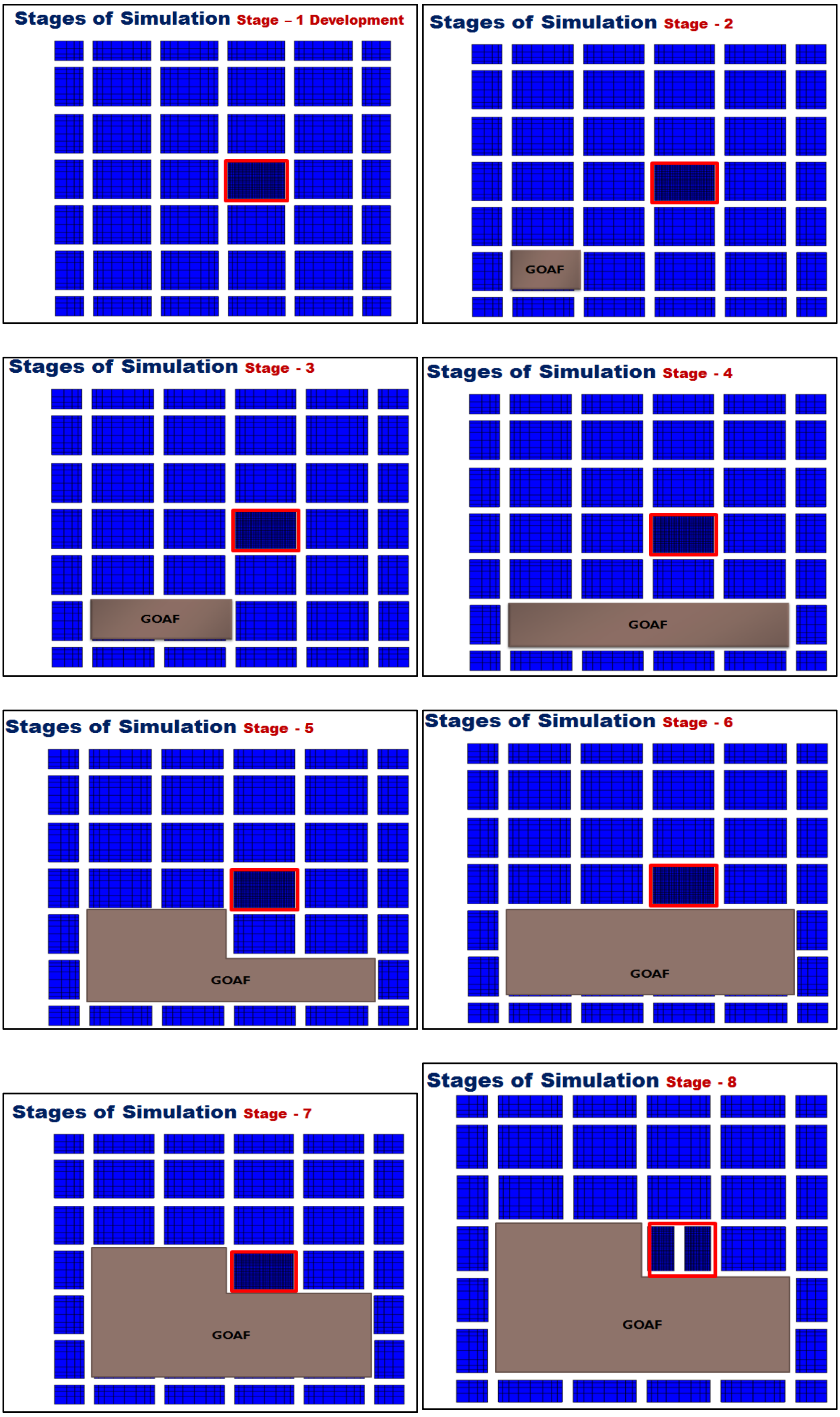
7.6.8 Simulation of model during development

After simulated the model in the in-situ condition, the gallery was developed and installed the rock bolt into the entire panel and simulate the model. The model response will give the information of yield zone (RLH) in the roof and axial load developed in each of the bolts. In this study, two cases have been discussed primary one is a simulation without the support, and the secondary one is a simulation with support using rock bolt. The support pattern will vary using the different bolt density discussed above.

7.6.9 Simulation of model at different stages of depillaring operation

In the depillaring operation, various stages are taken into consideration during the simulation process, as shown in figure 7.6.

The simulated studies have revealed that induced stress on pillar increases rapidly during extraction of the third row and two pillars. The main fall generally occurred in this zone. So, the focused study area is taken into consideration for all the stages of operation as marked in the figure7.6 given below. The discretization of this pillar is taken very fine. The response of roof behaviour in terms of yield zone and for the bolt, in terms of the axial load, has been observed in all the cases. The total number of the simulation model is one hundred and forty four, considering all the critical parameters with their variation illustrated in table 7.2. Based on all the results observed from the simulation of models, a mathematical relationship has been derived from giving the optimum support design for the smooth mining operation.


Stages of Simulation Stage – 1 Development
Stages of Simulation Stage - 2
GOAF
Stages of Simulation Stage - 3
GOAF
Stages of Simulation Stage - 4
GOAF
Stages of Simulation Stage - 5
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Stages of Simulation Stage - 8
GOAF

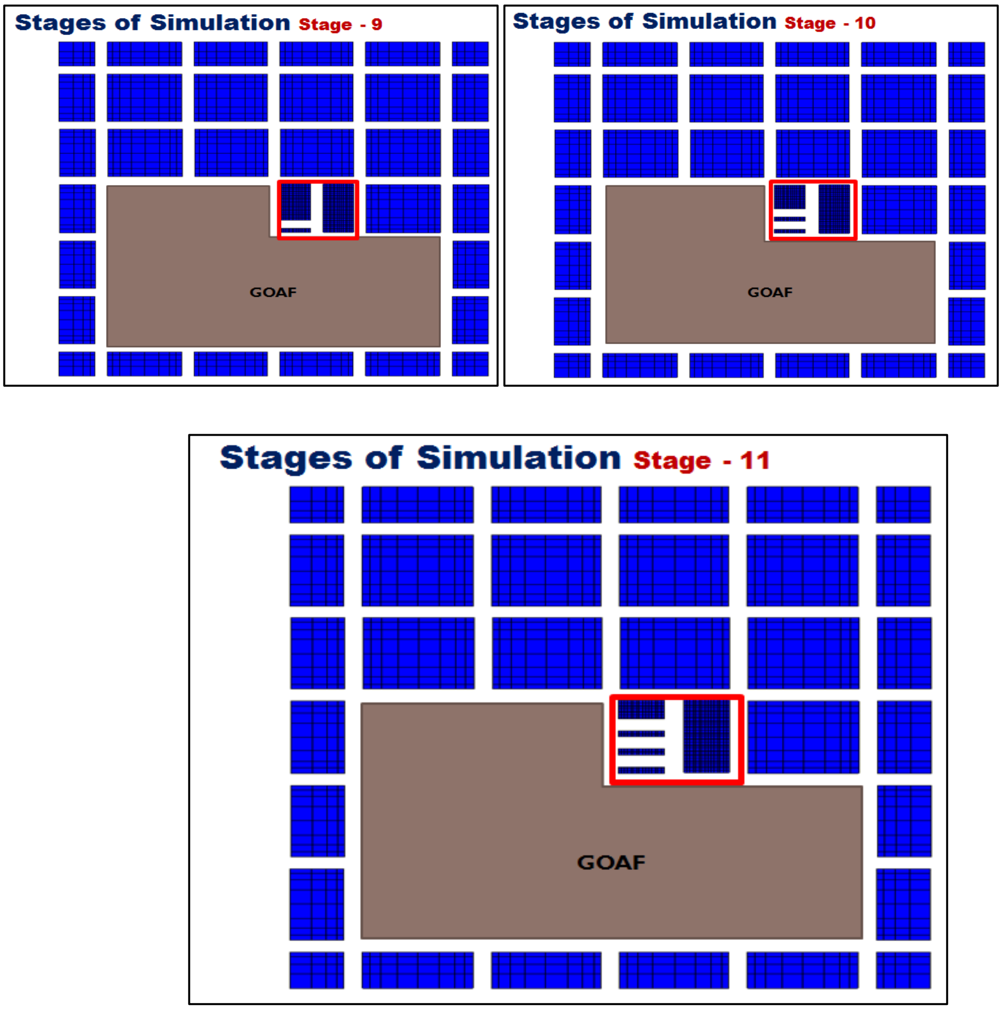

Figure 7.6 Various depillaring stages (Stage 1 to 11) of model considered for parametric studies

7.7 Summary

In this chapter, the discussion has been made considering various effects of important parameters in roof stability. The study has been carried considering four responsible parameters, i.e., depth of cover, RMR, bolt density, and gallery width. Total numbers of models are constructed considering different values of parameters. The range of each parameter has been taken based on different continuous miner operations in Indian coal mines.