Chapter 5

DESIGN PARAMETERS FOR CM PANEL

5.1.General

A proper design of intact pillars and remnant pillars is mainly required for a successful depillaring operation. The study aims to design the bord and pillar panel for mechanized depillaring. The panel design (considering working/barrier pillars) and the remnant pillars have been optimized in the study for different geo-mining conditions using numerical techniques. The parameters selected for designing the panel have been discussed in the subsequent sections.

5.2.Design of the panel

The panel of a bord and pillars mining system generally consists of five or six headings. The pillar width and the number of headings depict the panel width, whereas the length of the panel has been decided by considering the incubation period of the coal. A bord and pillar panel is mostly surrounded by the goaf from one side and developed pillars on the other. A straight line of extraction is generally preferred in a mechanized depillaring panel. The barrier pillars separating the active and goafed out panel were exposed to the goaf from both sides during the depillaring operation. The stability of the barrier pillars plays a major role in restricting the strata load from the nearby goafed out panel. The failure of these barrier pillars results in breakage of the strata's continuity, and excessive induced stress will be observed in the working area. As discussed in Chapter 3, the working pillar and barriers face maximum vertical stress at a critical depillaring stage where advancement length is equivalent to the panel width. An optimum panel design is considered the one in which the working pillar and barriers are stable at the critical depillaring stage. Numerical simulation techniques have been used in the study to determine the vertical stress and strength of the pillars (working and barrier pillars) under different geo-mining conditions. According to the design criteria, the *FOS* of the working pillar should not be less than 1.3, and the *FOS* of the barrier pillars towards the goaf side should be above 1.0 at the critical depillaring stage.

5.2.1. Design parameters for panel

An already developed scenario of bord and pillar system has been considered for the study. The panel design plays a vital role in an already developed panel as the size of pillars gets reduced in such panels during widening and heightening of galleries to facilitate the *CM* operation. Four different panels have been assessed in the study and each panel had a different pillar width (i.e., 26 m, 35 m, 45 m, and 48 m). The panel stability (formed by the selected pillars) has been accessed at a critical depillaring stage under different depths of cover ranging from 90 m to 450 m (with an interval of 30 m). Table 5.1 shows the parameters used in the study for optimizing the panel design.

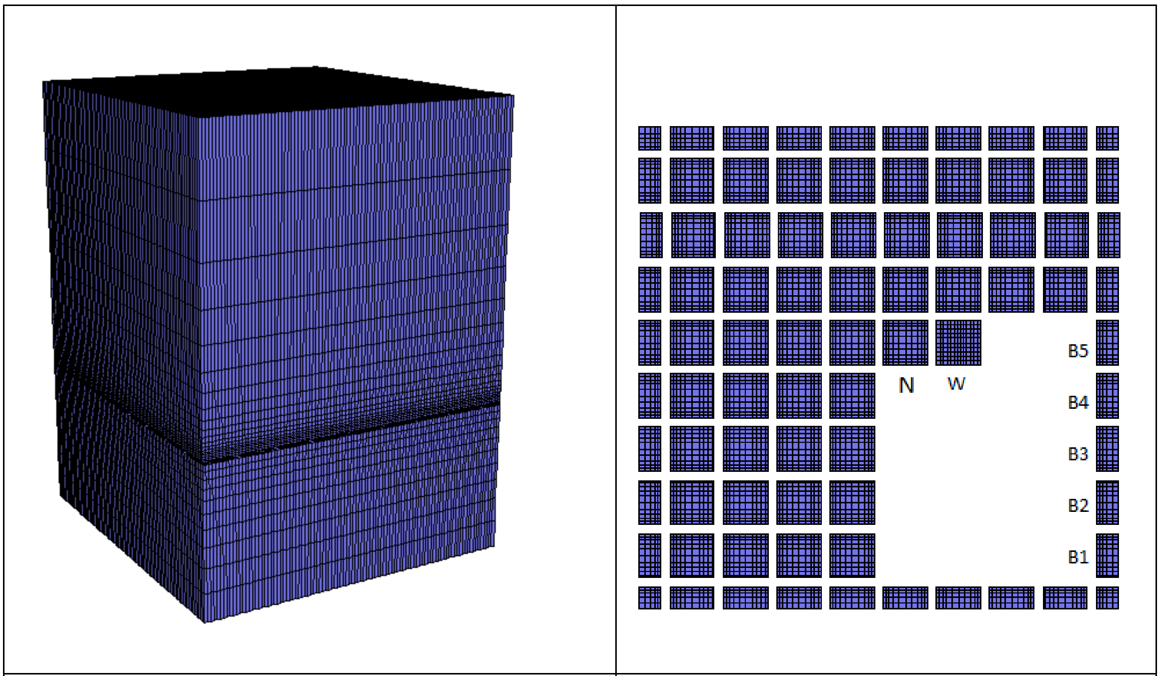
Table 5.1 Parameters used for designing the panel

Pillar width (m)	**Depth of cover (m)**	**Number of headings**
26	90, 120, 150	6
35	150, 180, 210, 240	5
45	240, 270, 300, 330, 360	5
48	360, 390, 420, 450	5

Usually, six headings were adopted in the panel having smaller pillars and five headings in larger pillars. In the present study, the panel formed by pillar width of 26 m consists of six headings, whereas panels formed by the pillar width of 35 m, 45 m, 48 m consist of five headings. The panels were classified into stable and unstable designs considering the design criteria. A critical depth of cover for each selected pillar has been identified using the simulation results.

5.2.2. Numerical simulation for panel design

A three-dimensional numerical model of a sufficiently large panel has been constructed in the study using *FLAC*^{3D}. The model comprises coal pillars, immediate strata, main strata, and floor. The roof in the model has been constructed up to the surface, considering the depth of cover. The thickness of the floor has been taken as 100 m. The panel consists of an 8 x 9 array of pillars (excluding the barrier pillars) in the model with the flexibility to vary the pillar width, depth of cover, and the number of headings for different combinations of the parameters mentioned in Table 5.1. The width and height of the galleries in the panel have been taken as 6.0 m and 4.5 m, respectively. The coal seam and roof have been joined with the 'attach' command of *FLAC*^{3D}. Fig. 5.1 shows the discretized view of the model.



a. Three-dimensional view | b. Plan view

Fig. 5.1 Discretized view of the model for panel design

The working pillar (Pillar P) has been discretized into ten equal parts in x and y directions with a discretization ratio of 1.0. The remaining pillars have a discretization ratio of 1.2 so that the sides of the pillars become more discretized than the core. Fig. 5.1a shows the three-dimensional view of the model. Fig. 5.1b shows the model's plan view at a depillaring stage where four and a half rows of pillars were extracted in a panel with five headings. The *UCS* of Indian coal mine generally varies from 20 MPa – 50 MPa. The *UCS* of the coal has been considered as 40 MPa for the study. The peak cohesion has been calculated using Eq. 3.3 (Chapter 3). The material properties for coal, roof, and floor have been used in the model, as discussed in Chapter 3. The base of the model has been fixed in the vertical direction, whereas all four sides in the normal direction. The top of the model is up to the surface level, hence, not fixed. The gravity component is acting normal to the coal seam in the model. The vertical stress and horizontal stress have been initialized in the model as per Eq. 4.1 and Eq. 4.3, respectively. The model has been simulated for different combinations of the parameters as mentioned in Table 5.1. The panels have been classified into stable and unstable cases considering the design criteria. A critical depth of cover has been identified in the study for each selected pillars by analyzing the simulation results.

5.3.Design of the remnant pillar

The depillaring operation begins with the extraction of pillars in the panel. Remnant pillars (ribs/snook) are left in the goaf during final coal extraction to provide temporary support to the strata. Remnant pillar design is of utmost importance for safe and productive mechanized depillaring operation as they are the only natural support present in the panel at the goaf edge. Over-sized remnant pillars delay the caving process, whereas under-sized remnant pillars may raise the overriding situation in the working area. The optimum remnant pillar design supports the overhang until the depillaring advances to a safe distance. The term '*Strength Factor (SF)*' has been coined in the study to assess the stability of the remnant pillars during the depillaring operation. The *SF* is the ratio of the residual strength of the remnant pillar and the weight of the overhang (Eq. 3.1). The optimum remnant pillar design is considered to be the one in which the *SF* of the previous extracted pillar/remnant is less than 1.0, and the *SF* of the working pillar/remnant is greater than 1.0, at a depillaring stage where the last slice has been taken out from the working pillar. Numerical techniques have been used in the study to determine the residual strength of the remnant pillars, and the weight of the overhang has been calculated considering the density and volume of the overhang (Eq. 3.2). The overhang density has been taken as 2500 kg/m^3. The volume of the overhang can be calculated by multiplying the overhang area by its thickness. In the present study, the overhang area has been considered one pillar size, and the thickness has been taken as 4.5 m (through field investigation). The optimum remnant pillar design is considered to be the one satisfying the design criteria.

5.3.1. Design parameters for remnant pillars

The remnant pillars for the four selected pillars (i.e., 26 m, 35 m, 45 m, and 48 m) have been designed in the study using numerical simulation techniques. The stability of the remnant pillars has been accessed in the study at a critical depillaring stage and critical depth of cover (as determined through the panel design exercise). Fish-bone extraction pattern has been adopted for pillar width of 26 m, split, and fender for a pillar width of 35 m, and double split and fender extraction pattern has been used for pillar width of 45 m and 48 m. The slices are taken out from the pillar at an angle of about 70°, resulting in a rhomboidal shape of ribs/snooks. Snook is the last natural support left in the goaf while taking the last slice from the pillar/fender. The size of the snook is generally larger than other ribs concerning safe mine workings. The optimum remnant pillar design has been obtained for each case of pillars by varying the snook width. Three different snook sizes (i.e., having resultant width of 4.5 m, 5.5 m, and 6.5 m) have been considered in the study to determine the optimum remnant pillar design for each selected pillars. Table 5.2 shows the parameters used for the remnant pillar design.

Table 5.2 Parameters used for designing the remnant pillar

Pillar width (m)	**Depth of cover (m)**	**Extraction pattern**	**Size of snook (m)**
26 m	D_{max}	Fish-bone	4.5 m, 5.5 m, 6.5 m
35 m	D_{max}	Split and fender	4.5 m, 5.5 m, 6.5 m
45 m	D_{max}	Double split and fender	4.5 m, 5.5 m, 6.5 m
48 m	D_{max}	Double split and fender	4.5 m, 5.5 m, 6.5 m

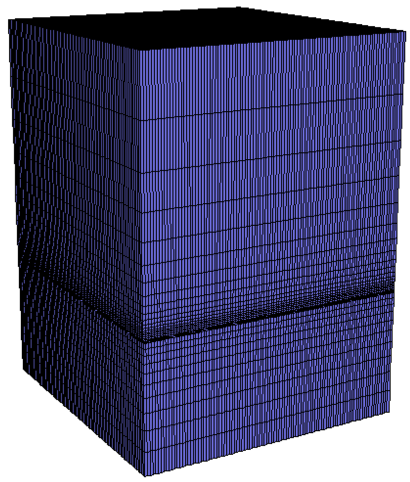
where D_{max} is the maximum depth of cover, up to which the panel is stable

5.3.2. Numerical simulation for remnant pillar design

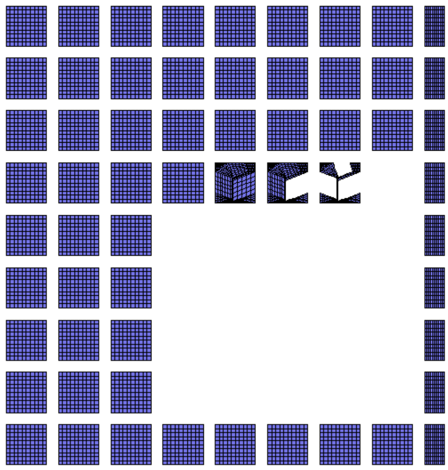
A three-dimensional numerical model of the panel has been prepared in the study using numerical simulation software, *FLAC^{3D}*. Brick elements have been used to build up the model that comprises intact pillars, remnant pillars, immediate strata, main strata, and floor. The model has been prepared for all the four selected pillars having widths of 26 m, 35 m, 45 m, and 48 m. The critical depth of cover (as obtained through panel design exercise) for each case of pillars has been adopted in the model. The panel consists of a 9 x 9 array of pillars for a pillar width of 26 m, and the panel has an array of 10 x 10 pillars for a pillar width of 35 m, 45 m, and 48 m. The width and height of the galleries in the model have been taken as 6.0 m and 4.5 m, respectively. The fish-bone pattern of extraction has been considered for the pillar size of 26 m. The split and fender extraction pattern has been adopted in a panel with a pillar width of 35 m and the double split and fender for pillar width of 45 m and 48

m. The previously extracted pillar, working pillar, and the immediate next pillar in the fish-bone pattern have been constructed so that the slices can be taken out from three sides of the pillar at different stages of depillaring. The previously extracted pillar and the working pillar have been constructed for split and fender, and double split and fender pattern of extraction; so that splits can be made, and slices can be taken out from the fenders at each stage of depillaring. An immediate stratum has been constructed above the pillars/remnant such that it forms a cantilever up to the previously extracted pillar. The nodes of the coal pillars and ribs/snook have been attached with the immediate strata using the 'attach' command of $FLAC^{3D}$. The main strata have been constructed up to the surface level. The thickness of the floor has been taken as 100 m. The immediate strata and the main strata have been separated in the model using an interface. Fig. 5.2 shows the discretized view of the model. Fig. 5.2a shows the three-dimensional view of the model, and Fig. 5.2b, Fig. 5.2c, and Fig. 5.2d show the panel's plan view at the mid-level of the pillars with different extraction patterns. The discretization ratio of the pillars (except the focused pillars) in the case of the smaller pillar (i.e., pillar width of 26 m) has been taken as 1.0. The discretization ratio for larger pillars (i.e., pillar width of 35 m, 45 m, and 48 m) has been taken as 1.2 such that sides of the pillars have been closely discretized than the core.

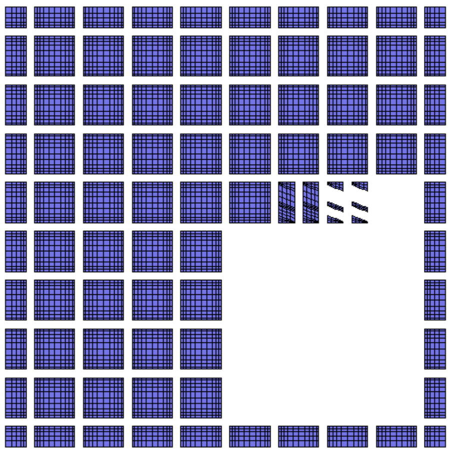
The *UCS* of the coal has been considered as 40 MPa for the study. The peak cohesion value has been calculated using Eq. 3.3 (Chapter 3). The material properties of coal and other strata have been incorporated in the model, as discussed in Chapter 3. The model's base has been fixed in the vertical direction, whereas all four sides in the normal direction. The top of the model is up to the surface level, hence, not fixed. The gravity component is acting normal to the coal seam in the model. The vertical stress and horizontal stress have been initialized in the model as per Eq. 4.1 and Eq. 4.3, respectively.



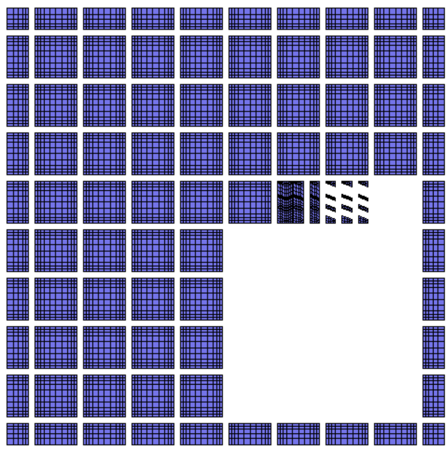
a. Three-dimensional view



b. Fish-bone pattern



c. Split and fender pattern



d. Double split and fender pattern

Fig. 5.2 Discretized view of the model for remnant pillar design

The models have been simulated for a critical depillaring stage at which the advancement length is equivalent to the panel width or depth of cover, whichever is lesser. The simulation has been carried out for different stages of slicing. The panel with a pillar width of 26 m has been simulated for four depillaring stages ('Stage I' through 'Stage IV'), whereas the panel having a pillar width of 35 for six depillaring stages ('Stage 0' through 'Stage V'). The panel has a pillar width of 45 m, and 48 m has been simulated for twelve different depillaring stages ('Stage 0' through 'Stage XI'). The models have simulated until the attainment of the equilibrium conditions.

5.4.Concluding remarks

A detailed parametric study has been conducted to design the panel and remnant pillars for mechanized depillaring. Four pillars have been selected for the study, i.e., pillar width of 26 m, 35 m, 45 m, and 48 m. The stability of the panels (formed by the selected pillars) has been accessed for different depths of cover ranging from 90 m to 450 m, with an interval of 30 m. Numerical simulation techniques have been used in the study for this purpose. The maximum depth up to which the panel is stable has been determined in the study, considering the design criteria. Further, the remnant pillars formed during the final extraction of the selected pillars have been designed at a critical depth of cover (as obtained from the panel design exercise). The snook size has been varied in the study to determine the optimum remnant pillar design for the selected pillars. Numerical models of the sufficiently large-sized panel have been prepared in the study for each selected pillars and simulated sequentially with a different combination of snook size. The optimum panel and remnant pillar design have been considered to be the one satisfying the design criteria.