Coal is a primary source of energy and plays an essential role in economic development of a country. India is a country having abundant coal deposits (about 155.61 BT of proven coal). The current trend of coal mining tends towards underground practices as opencast mines arise several environmental and health hazards. The bord and pillar is the most commonly used method of underground coal mining in India. Development and depillaring are the two phases of the bord and pillar system. The coal is extracted by driving galleries in the development phase. The depillaring operation has been commenced in the panel by the extraction of the pillars. Mechanization is proving to be an effective way to increasing underground coal production. The *CM* technology introduces in India in the year 2003 at Anjan Hill mine, *SECL*. Afterward numbers of mines have adopted *CM* technology to increase underground coal production. Strata issues have arisen in few Indian coal mines which deploy *CM* in an already developed panel for the depillaring operation. The widening and heightening of the galleries in an already developed panel (for easy maneuvering of the machine) reduces the designed factor of safety (*FOS*) of the pillars and may raise the strata issues. The intact pillars and remnant pillars (ribs/snook) are the critical elements of a depillaring panel, and the stability of these elements dictates the success of the depillaring operation. The *CM* is mass production technology; thus, a holistic design approach considering pillars (including barriers) and remnant pillars may help in achieving safe and productive mining operations. Numerical techniques are widely used nowadays in the field of geotechnical to deal with complex geo-mining conditions. An attempt has been made in the study to design the bord and pillar panel for mechanized depillaring using numerical techniques.

An extensive literature survey has been carried out in the study concerning the strata behavior, extraction patterns adopted during final coal extraction using *CM*, and the designing techniques. The bord and pillar panels are generally surrounded by goaf from one and developed pillars on the other. The barrier pillars, which are surrounded by the goaf from both sides, are the critical pillars, as the failure of these pillars may beak the continuity of the strata and result in extreme loading conditions in the

working area. The pillars nearby goaf show high-stress conditions before the occurrence of the main roof fall. The main roof fall area generally varies from mine to mine, depending on the nature of the overlying strata. The maximum stress conditions arise in the panel at a depillaring stage in which the advancement length is equivalent to the panel width considering no main roof fall until that stage. The working and barrier pillars are required to be stable until the main roof fall occurs for maintaining the global stability in the panel. The optimum panel design is considered to be the one in which the working and barrier pillars are stable at the critical depillaring stage, where advancement length is equivalent to the panel width.

Numbers of extraction patterns have been adopted during the mechanized depillaring operation considering the pillar size. Fish-bone and split, and fender are the commonly used pattern adopted during final coal extraction using *CM*. The slices are taken out at an angle of about 70° while adopting *CM* technology considering the machine maneuverability. Rhomboidal-shaped remnant pillars (ribs/snooks) are left in the goaf during final coal extraction using *CM*. The overlying strata in underground coal mines are present in the form of layers or beds. The immediate strata separate from the main strata during the final coal extraction and impose their load on the remnant pillars. The required stability of the remnant pillars is to bear the load of the immediate strata until the depillaring advances to a safe distance and fails afterward to enable the caving process.

A smooth mechanized depillaring operation can only be achieved if the intact pillars (including barriers) and remnant pillars (ribs/snook) of the panel are wisely designed. The factor of safety (*FOS)* approach has been adopted in the study for designing the pillars. The design criterion for the pillars states that the *FOS* of the barrier pillars (which are surrounded by the goaf from both sides) should be greater than 1.0, and the *FOS* of the working pillars should not be less than 1.3 (preferably more than 1.5) at the critical depillaring stage. The term *'Strength factor* (*SF*)' has been coined in the study to assess the stability of the remnant pillars. The ratio of residual strength of the remnant pillars and the weight of the overhang is termed as *SF*. The design criteria for the remnant pillars states that the *SF* of the working pillar ‘W’ should be greater than 1.0 until last slice has been taken out from the pillar, and at that depillaring stage the *SF* of the previously extracted pillar ‘P’ should be less than 1.0.

Numerical techniques have been used in the study to design the panel for mechanized depillaring. Numerical modeling software, $FLAC^{3D}$, has been used in the study for this purpose. The numerical model has been prepared in the study using brick elements. Coal is a strain-softening material; thus, assigning appropriate material properties is the prime requirement of a numerical model. The published cases of failed and stable pillars from Indian coal mines have been used in the study to calibrate the material properties for the coal. A linear expression has been observed between the peak cohesion value and the *UCS* of coal.

The derived properties of the model have been validated with three field cases of Indian coal mines where *CM* technology has been adopted in an already developed panel. The depillaring stage at which the strata issues emerge in the model has been identified using simulation results. The models have been validated using field observations and the instrumentation records during the depillaring operation. The analysis of the simulation results shows that the *FOS* of the working pillar should not be less than 1.3 for safe depillaring operation. The analysis of the rock instruments records shows that the stand-up time of the remnant pillars is about 45 hours.

The designing of the mechanized depillaring panel has been carried out in two phases, i.e., designing the panel (concerning working/barrier pillars), and designing the remnant pillars (ribs/snook). Four different pillar sizes have been selected from Indian *CMR*, 2017, i.e., having pillar widths of 26 m, 35 m, 45 m, and 48 m. The width and height of the galleries have been chosen as 6.0 m and 4.5 m, respectively. Numerical models of sufficiently large size have been prepared for each selected pillars and simulated for different depths of cover ranging from 90 m – 450 m (with an interval of 30 m). The derived material properties have been incorporated in the model, considering the *UCS* as 40 MPa. The prepared models for different combinations of pillar width and depth of cover have been simulated until attaining the equilibrium conditions. The simulation results have been obtained in terms of vertical stress profile and yield profile. The average vertical stress on the working/barrier pillars has been determined for each case of the panels using *the FISH* function of $FLAC^{3D}$. The stable cases of the panels satisfying the design criteria have been identified and chosen for the analysis. The '*Stress ratio (SR)*,' (i.e., the ratio of average vertical stress on the pillars during depillaring and development), has been calculated for all the stable cases of the panels. The simulation results show a wide range of *SR* values for different depths of cover. The analysis of the results shows that *SR* is linearly related to the *FOS* of the pillars during development. An expression has been developed to determine the *SR* of a pillar using its *FOS* during development. A nomograph has also been developed in the study, depicting the optimum width of the pillar for a mechanized depillaring panel for different depths of cover and extraction heights.

The panels formed by the selected pillars (i.e., having a width of 26 m, 35 m, 45 m, and 48 m) has been further simulated at a critical depillaring stage by incorporating the remnant pillars such that splitting/slicing of the working pillar can be performed at different stages. The models for each selected pillar have been simulated at the critical depth of cover (determined through panel design exercise). The design of the remnant pillars has been optimized for selected pillars by varying the size of the final snook (i.e., 4.5 m, 5.5 m, and 6.5 m). The simulation results have been obtained in terms of vertical stress profile and yield profile. The residual strength of the remnant pillars has been determined for each case of selected pillars at different stages of splitting/slicing using *FISH* function of $FLAC^{3D}$. The last stage of slicing for each selected pillars, satisfying the design criteria, has been chosen for the analysis. The analysis of the results shows that the load-bearing capacity of the remnant pillar is exponentially related to its area. An expression has been developed from the analysis to determine the load-bearing capacity of the remnant pillar based on its area. It has also been analyzed from the results that during the last stage of slicing, the residual strength of the working pillar/remnant 'W' is about 0.6 MPa, and the residual strength of the previously extracted pillar/remnant 'P' is about 0.4 MPa for safe mine workings. The analysis shows that the percentage of extraction is about 80% for an optimum remnant pillar design. It has been concluded from the analysis that the final snook is about 5% of the pillar area for a smaller pillar and about 8% for larger pillars. Guidelines have been provided in the study to design the remnant pillars for different pillar sizes.