Chapter 1

INTRODUCTION

1.1.General

India is one of the world's largest economies, and coal plays a vital role in its economic development. Coal dominates India's energy consumption matrix and also plays a vital role in the generation of electricity. India constitutes about 9.4% of the world's total coal reserves (Spencer et al. 2018), with a proven coal reserve of about 155.61 BT. Despite having abundant coal deposits, the country is still facing a gap in the demand and supply of coal. Domestic production from both opencast and underground coal mines is unable to meet the requirements resulting in massive coal imports. About 45% of India's coal mines are underground, but their production percentage is relatively low, i.e., about 6% (Annual report, 2019-20, *MOC*). The opencast mines' production always dominates the underground mines in the country. A wider gap in the degree of mechanized in opencast and underground mines of the country is the main reason behind opencast coal production's dominancy. The current trend of coal mining is tending towards underground practices considering the rise in environmental and health issues due to opencast mining practices. Depletion of shallow coal deposits enforces the coal industry to adopt extensive underground practices to extract the coal at a faster rate to meet the demand. Mechanization is the only way to increase domestic coal production as mechanized mines can meet the desired targets and fill the demand-supply gap.

The underground mining of coal adopts a panel system of working to extract the coal, and bord and pillar is a preferred method of underground coal mining in India, considering the geo-mining complexities. Development and depillaring are the two phases in the bord and pillar system. Coal is extracted by driving the galleries and leaving pillars during the development phase, and pillars are extracted in the depillaring stage, leaving remnant pillar (ribs/snook) for temporary support.

The Indian coal mine sector has seen several technological advancements in mining operations (Longwall and CM system) in the last two decades to effectively extract and utilize its vast coal deposits and minimize the gap between the demand and supply of coal. Mechanization has been extended nowadays in many underground coal mines of the country. The country is adopting *CM* technology in bord and pillar panel of Indian coalfields to extract the coal at a faster rate. It has been observed that the average coal production from a *CM* panel ranges from 1200 – 2000 tonnes/day, based on the discussion with mine officials of various Indian coal mines. Mechanized depillaring operation using *CM* begins in India in 2003 at Anjan Hill mine, *SECL*, a *CIL* subsidiary (Singh et al. 2006). The successful field trial of the machine (*CM*) encourages the industry to adopt the *CM* technology the bord and pillar system. Many already developed panels of underground coal mines of the country also adopt the *CM* technology for the depillaring operation. Extraction of the coal using *CM* is quite different from the conventional techniques of drilling and blasting. The safety risk during mechanized depillaring is relatively high as compared to conventional depillaring practices. The pillars in an already developed panel are designed as per Indian *CMR*, 2017. Adopting *CM* technology in an already developed panel requires a widening of the galleries for easy maneuvering of the machine. Heightening of the galleries can also be performed considering the thickness of the coal seam. The widening and heightening of galleries in an already developed panel before depillaring reduces the designed *FOS* of the pillars. Strata issues have been observed in numerous underground mines of the country adopting *CM* technology during the depillaring operation. Hence, proper designing of such panels is required for safe and productive coal extraction from underground coal mines of the country.

1.2.Motivation for the study

The underground mining activity disturbs the natural state of equilibrium. Most of the country's underground coal mines prefer caving of the strata during final coal extraction to resume the stable state of equilibriums by releasing the strata pressure. The biggest challenge in underground coal mining is synchronizing the caving process with the advancement in depillaring operation. Pillars (including barriers) and remnant pillar are the critical elements of the depillaring panel, and their design plays an essential role in achieving safe and productive depillaring operations.

Pillar stability has been an area of grey research for more than a decade (Holland 1964, Salamon and Munro 1967, Sheorey and Singh 1974, Sheorey 1992, Mark 2000, Van-der-Merwe 2003, Jaiswal and Shrivastva, 2009). The researchers have developed a number of empirical relations to determine the strength of the pillars under different geo-mining conditions. The pillars in bord and pillar mining system are designed as per Indian *CMR*, 2017, with a maximum allowable gallery width of about 4.8 m. As discussed earlier, the *CM* working requires a gallery width of about 5.5 m – 6.5 m for easy maneuvering of the machine. The guidelines to design the pillars for a mechanized depillaring panel adopting *CM* technology have not been developed by any researcher, hence been attempted in the study.

Few researchers have attempted to determine the stability of the remnant pillar (ribs/snooks) (Mark and Zelanko 2001, Van-der-Merwe 2005, Singh et al. 2016, Chawla et al. 2017) using analytical and numerical techniques. Remnant pillar are the ribs/snooks left during final extraction of the coal for temporary support of the strata. Singh et al. (2016) have attempted to design the snook for Indian coalfields using numerical techniques and provided an empirical relation considering the depth of cover and RMR of the strata. Mark and Zelanko (2001) have performed the study on *US* coalfields for designing the snook and states that the size of the snook is independent of the depth of cover. Van-der-Merwe (2005) adopted the beam – cantilever theory and provided an analytical solution to design the snook based on South African coalfields. As discussed earlier, the design of a snook plays an important role in providing safe and productive depillaring operation and hence requires more extensive research to reduce arise of strata issues during the final extraction of coal. Numerical techniques are widely used nowadays in the mining sector to design structures. A three-dimensional numerical simulation of the underground structures (like pillars/ribs/snooks) provides an overview of the working area's stress environment and helps in optimizing the design. The analytical solution provided by Van-der-Marwe (2005) can be optimized using technological advancement in terms of numerical techniques.

Researchers have generally attempted to design the pillars or ribs/snook individually for the bord and pillar mining system. Designing the mechanized depillaring panel holistically, concerning the intact pillars (including barriers), and remnant pillar (ribs/snooks) can resolve the strata issues to a large extent that arise during the depillaring operation.

1.3. Objective of the study

The primary objective of the study is to design the structures of a mechanized depillaring panel holistically concerning the design of pillars (including barriers) and remnant pillar using numerical techniques. Following are the sub-objectives of the study to fulfill the main objective:

i) Development of the methodology for designing the panel and remnant pillar.

ii) Assessment of coal mass strength parameters

iii) Development of numerical model for field cases and their validation

iv) Development of numerical model for optimum design of the panel under different geo-mining conditions.

v) Development of a nomograph showing optimum size of the pillar under different geo-mining conditions.

vi) Development of numerical model for optimum design of the remnant pillar (ribs/snook) under different geo-mining conditions.

vii) Development of guidelines for designing the remnant pillar under different geo-mining conditions.

1.4. Outline of the thesis

For detail and sequential presentation of the whole work, the thesis has been organized into seven chapters:

Chapter 1: The first chapter provides a brief introduction about the importance of the study in the present mining scenario. The research gap in the concerned area has been identified, which gives the motivation for the study. The objectives have been set for the study to design the mechanized depillaring panel using numerical techniques. The structural outline of the thesis has also presented in this chapter.

Chapter 2: The second chapter provides an extensive literature review concerning a mechanized depillaring panel. A detailed study concerning the strata behavior, extraction patterns, and the designing techniques for intact pillar and remnant pillar have been discussed in this chapter.

Chapter 3: The third chapter discusses the methodology adopted for designing the mechanized depillaring panel. Numerical simulation techniques have been used for this purpose ($FLAC^{3D}$). Design criterion for an optimum pillar and remnant pillar design has been proposed in the study. The coal mass strength parameters have been determined using failed and stable cases (published) of coal pillars from Indian coalfields.

Chapter 4: The fourth chapter discusses the field cases selected for the study, numerical simulations for each selected case, and their validation. Three cases of the bord and pillar panels adopting mechanized depillaring have been selected for the study. Numerical models were prepared for each case of panels and simulated sequentially with a straight line of extraction. The models were validated using strata instruments and field observations during the depillaring operation.

Chapter 5: The parameters adopted for designing the panel and remnant pillar have been discussed in the fifth chapter. The study has been carried out in two phases, i.e., a) Designing the panel and b) Designing the remnant pillar. Numerical models have been prepared for designing the panel and simulated at a critical depillaring stage for different combination of pillar widths and depth of cover. The designing of the remnant pillar has been commenced by simulating the panel at a critical depillaring stage and depth of cover for different combination of pillar width and snook widths.

Chapter 6: The simulation results in terms of vertical stress and yield profile for all the models have been presented in the sixth chapter. The cases of panels and remnant pillar satisfying the design criteria have been chosen for further analysis. Based on the analysis, a nomograph has been prepared for the panel design. The guidelines for designing the remnant pillar design were also provided in this chapter.

Chapter 7: Significant outcomes drawn from different chapters and contributions from the study has been summarized in the seventh chapter.