

Chapter 1

Introduction

1.1 General

Underground coal mines with bord and pillar method of working play an important role in coal-producing countries like India, China, the U.S. and South Africa (Murali Mohan et al. 2001; Peng 2007; Yu et al. 2017). In India, bord and pillar mining method contribute more than 79.7% of coal production (Sourav Mukherjee 2019). Bord and pillar mining involves creating a network of galleries called bords and leaving solid coal as pillars to support the roof during the development stage. During the depillaring phase, these pillars are systematically extracted, allowing controlled roof collapse. If important surface structures/futures are present, then it is preferable to adopt either partial extraction or depillaring with the stowing method to minimise the effect of subsidence so that the surface structures/futures will be stable. Bord and pillar with caving method is being preferred where important structures/futures are not present at the surface. This process demands meticulous planning and an understanding of rock mechanics to prevent unexpected strata behaviour and ensure miner safety. Thus, it is important to assess the stability of underground structures (i.e. pillars and the roof) in an underground mine. The stability of the underground structures depends on various factors, including the size and shape of the pillars, strength, stress acting on pillars, the sequence of pillar extraction, and the geological characteristics of the roof and floor. The numerical simulation technique is one of the best tools to assess the strength and stress acting on the pillar. The numerical simulation models require appropriate constitutive models for strata (coal-mass and other

strata) and a goaf/ caving simulation approach specifically for caving panels. This technique is used to design for stability assessment of underground structures.

1.2 Background and Motivation

Pillar stability and caving behaviour during depillaring operations have been a grey area in research. Empirical and numerical simulation techniques were used to estimate the pillar's strength. However, all these equations are static and derived for long-term stability without considering the effect of time. The most appropriate constitutive models representing the coal-mass are strain-softening considering either the Mohr-Coulomb or Hoek-Brown failure criterion. This model is assigned to the coal pillar for stability assessment. These constitutive models do not consider the effect of time. However, it has been observed that the strength of the pillar decreases with time. Most of the constitutive models available to study the strength deterioration with respect to the time of a coal pillar are considered for small scale with limited time.

Caving simulation is another very important issue/challenge for numerical analysts for assessment of the stress in a depillaring panel. There are various approaches for the simulation of caving behaviour, such as removing and replacing the extracted portion or roof up to caving height with goaf material with a logical process. These approaches are implicit in nature and require continuous monitoring of the strata behaviour to decide the goaf filling sequence, goaf compaction behaviour, etc. Keeping these two challenges, a proper time-dependent constitutive model and simplified caving simulation approach are required for proper assessment of the stability of underground structures.

1.3 Objectives of the Study

Assessment of the stability of underground structures is a prime concern of this thesis for bord and pillar panels using numerical simulation techniques. Keeping the two most important challenges as discussed in section 1.2, the following objectives are defined:

- a) Development of Hoek-Brown time-dependent constitutive model for coal-mass
 - i) Estimation of Hoek-Brown time-dependent strength parameters by back-analysis techniques using field cases.
 - ii) Time-dependent pillar strength formula
- b) Development of the explicit caving simulation approach
- c) Implementation of the explicit approach for suggesting a design criterion of an underground bord and pillar panel of a typical case.

1.4 Structure of the Thesis

Chapter 1: Introduction

The introduction chapter provides an overview of the research topic and its significance. It outlines the research problem, research objectives and research questions. The research gap in the concerned area has been identified, which motivates the study. The objectives of the study are to develop a time-dependent constitutive model for coal-mass and the explicit caving approach of a depillaring panel. The chapter concludes by outlining the structure of the thesis and providing a roadmap for the subsequent chapters.

Chapter 2: Literature Review

The literature review chapter is divided into two main sections. These two sections present a comprehensive review concerning the time-dependent behaviour of the coal-

mass and strata behaviour (pillars and roof) during depillaring operations. The chapter critically examines the gaps and limitations of the existing approaches. It sets the foundation for the research by identifying the current state of knowledge and guiding the research hypotheses.

Chapter 3: Methodology

In this chapter, a time-dependent strain-softening constitutive model has been proposed based on the time-dependent pillar failure analogy. Implementation of the proposed constitutive model in the FLAC^{3D} (based on FDM) has also been discussed. A simplified caving simulation approach resembling the natural caving process has also been proposed.

Chapter 4: Constitutive model for coal-mass

This chapter discusses the numerical simulation process for finding the strength parameters of the proposed time-dependent constitutive model for coal mass. The field cases of South African collieries have been chosen for assessment of the strength parameters by using back-analysis.

The strength parameter of Indian cases has also been assessed. A time-dependent pillar strength formula has also been proposed.

Chapter 5: Numerical simulation of depillaring panel

This chapter presents the details of a case study and the field observations of a bord and pillar panels (consisting of three panels). It provides details of the numerical model and simulation scheme by considering the proposed caving simulation scheme. The model has been constructed in such a way that individual pillars can be extracted sequentially.

Chapter 6: Results and Analysis

This chapter presents findings from the numerical simulation in terms of caving behaviour and vertical stress profile on the pillars for each depillaring stage. The stability of the pillars was also assessed based on FOS (i.e. strength/stress). The strength of the pillar was estimated by using the proposed time-dependent pillar strength formula. The stress was assessed using a numerical simulation of the depillaring panel. The finding of panel B has been validated with the field observations. Further, panel C has been designed based on the numerical simulation study.

Chapter 7: Conclusion

This chapter contains the significant findings of this study and suggestions for future work. The conclusion chapter summarises the key findings, contributions and implications of the study.



