CHAPTER 1

INTRODUCTION

1.1. Introduction

The mining sector has a significant contribution to the national economies. Underground and surface (Open-pit/Opencast) mining are the two primary methods based on the different feasibility criteria. Currently, the open-pit mining method is majorly adopted as it has 3-5 times higher productivity, offers a possibility for the upgradation of the mining technologies, lower production cost, and safer and larger mineral recovery when compared with the underground mining method (Altiti et al. 2021). Still, a few hurdles decelerate the productivity of such workings.

1.2. Background

The higher demand for minerals has forced the mining management to go deeper into the surface mines. The increased depth has increased the stripping ratio, which caused the generation of a vast volume of overburden (OB)/waste rock material (Gupta et al. 2021). Wagner (2021) analyzed the existing condition of the opencast mines and mentioned that the general stripping ratio varied from 2:1 to 5:1 and could be as high as 15:1. The Mount Owen Coal Mine, Hunter Valley, Australia, has a stripping ratio of 4.51 (Owen and Operations 2019). In Europe, the stripping ratio varied from 2.2:1 to 9.5:1 m^3/te (EY 2014, Bednarczyk Z 2016). In Indian coal mines, the average stripping ratio was 2.75 during the financial year 2021-22. Figure 1.1 depicts a significantly increasing generation of OB vis-à-vis India's coal production in the last decade (Provisional Coal Statistics 2022).

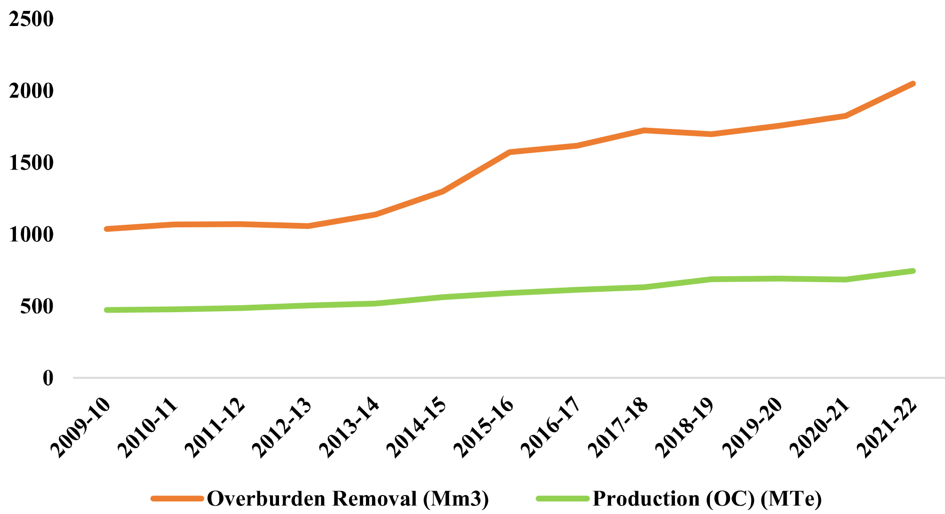

Fig. 1.1 Trend of overburden removal and coal production during 2009-22 (Provisional Coal Statistics 2012; 2015; 2018; 2022)

Generating a massive volume of OB requires ample dumping space for its safe storage. Rapid development, urbanization, population growth, and social and environmental issues are affecting the future availability of land for mining activities (Bloodworth et al. 2009). The existing leasehold area cannot accommodate such a massive volume of OB material. Even though mine management usually makes all the efforts, land acquisition is still a long and tedious process. Thus, the scarcity of OB dumping land is one of the major problems for managing opencast mines today.

Under the prevailing conditions, the mine is required to accommodate the ever-increasing volume of the OB material within the available limited space. Large-size dump slope structure in limited space is prone to failure, aggravated by several parameters that push the instability of such structures. Table 1.1 shows the consequences while Table 1.2 summarises the amount of material involved in such failures. These data depict that the dump slope instability has been recurring for a long. Hence, a reliable design of the dump slope structure is essential.

Table 1.1 Statistics of the consequences of waste rock slope instability

Mine	Year	Loss	Reference
Wai Khar Jade mine, Hpakant, Myanmar	2020	More than 172 fatal	Lin et al. (2021)
Hpakant, Kachin state, Myanmar	2018	More than 22 fatal	Lin et al. (2021)
Rajmahal, India	2016	23 fatal and loss of machinery	Satyanarayana et al. (2017)
Basundhara, India	2013	14 fatal	Behera et al. (2016)
Kulda, India	2013	13 fatal	Satyanarayana et al. (2017)
Inez, Kentucky, USA	2002	Environmental damages	Blight and Fourie (2005)
Kawadi, India	2000	10 fatal	DGMS (2010)
Quintette Mrmot, BC, Canada	1985	2.50 km of river valley gets filled with waste dump and causes several environmental damages	Blight and Fourie (2005)
Buffalo Creek, USA	1972	118 fatal	Fahey et al. (2002), Blight and Fourie (2005)
Aberfan, Wales, UK	1966	144 fatal	Bishop (1973), HMSO (1967)

Table 1.2 Statistics of displaced material during failure of dump slopes

Mine	Year	Displaced material, Mm^3	Reference
Guangming, Shenzhen, China	2015	2.51	Zhan et al. (2018)
Singareni Colliery, India	2009	33.7	Poulsen et al. (2014)
South Field, Greece	2005	40	Steiakakis et al. (2009), Gabriel and Scott (2011)
Zhujiabaobao, China	1993	0.60	Bao et al. (2019)

Fording River Mine, Elkford, British Columbia	1989	3.9	Dawson et al. (1998)
Quintette Coal, Tumbler Ridge, British Columbia	1985	2.5	Dawson et al. (1998)

The slope stability analysis started with the Limit Equilibrium Method (LEM). There are many methods based on LEM as reported by Fellenius (1936), Janbu (1954), Bishop (1955), Morgenstern and Price (1965), Spencer (1967), and Generalized Limit Equilibrium (Lam and Fredlund 1993), Nguyen et al. (1984). LEM is widely used because of its speed, accuracy, and simplicity (Duncan 2014). However, it does not consider the stress-strain relationship (Pasternack and Gao 1988; Low 1997; Pascoe et al. 1998).

Numerical modeling with the Strength Reduction Method (SRM) is being utilized as a primary method as it can assess the critical slip surface and satisfy rotational and translational equilibrium conditions (Pariseau et al. 1997; Gupta et al. 2021). However, it is time-consuming, expensive, complex, and requires prerequisite skills (Abdalla et al. 2015; Koopialipoor et al. 2019; Gupta et al. 2022). Although this method has reduced the computational error, the simulation of the inherent variability in the dump material properties, their assimilation in the numerical model, and their overall impact on the results of dump slope stability is still a challenge.

1.3. Scope and Objectives

The instability of the dump slope structure is critical in the working of an opencast mine. Despite many efforts towards mitigating the impacts of slope instabilities, the methodology for the design of an optimally safe dump slope structure is still not fully established. The stability of the dump slope is a complex phenomenon depending on several independent and interdependent parameters. Hence, the objectives of this dissertation are to

- identify the critical parameters governing dump slope stability and assess their influence on the stability of the dump slopes,
- develop a stability classification system to assess the state of stability and impending hazard for the dump slope structures, and
- establish an approach for the design of long-term stable dump slopes.

This research is purely dedicated to the Indian coal mine's internal OB dump slope structures. FLAC 2D, Version 7.0 (FLAC, 2011) software with Mohr–Coulomb failure criterion was adopted for the dump slope stability analysis. This research provides an improved understanding of the parameters affecting slope stability. It also provides a classification system to define the stability state of a given dump slope structure, based on the output of numerical modeling. The influence of uncertainty in the geotechnical properties of OB material on the dump slope stability has been analyzed in terms of the probability of failure. Further, a design criterion has been suggested for long-term stable dump slopes. These outcomes would assist in the design of a reliable dump slope structure through an inexpensive ready-to-use solution that a mine operator can easily utilize.

1.4. Organization of the Thesis

Chapter 1 discusses the requirements of the proposed research work for the mining industry. It comprises the background, scope and objectives, and thesis organization.

Chapter 2 reviews the pertinent literature on the dump slope stability governing parameters, dump slope stability and hazard classifications based on stability rating, factor of safety, and the relationship between safety factor and probability of failure. The details of dump material characterization and @RISK software are also described. The significant gaps in the prevailing knowledge base are also underlined in this chapter.

Chapter 3 explains the essential steps and their significance in achieving the objectives of this study. It details the range of stability governing parameters, performance assessment indicators of numerical modeling, statistical model, and hazard quantification. The requirement of the stability state classification criteria is also discussed. The procedure of the parametric study of the mechanical, water table, and hazard quantification associated studies is further elaborated.

Chapter 4 describes the results of an experimental parametric study to assess the effect of stability governing parameters on the dump slope stability.

Chapter 5 describes the accuracy of the statistical model, sensitivity of horizontal displacement and shear strain increment against the factor of safety. The design limits of the output parameters and the extent of failure in different stability states are also discussed. The impact of the water table is also discussed in this chapter.

Chapter 6 details the development of stability rating and hazard quantification system. It summarises the selection of random and deterministic variables among slope stability parameters. The suitable probability distribution function for random variables for the design of a stable dump slope is defined. The procedure for estimating the rating and hazard vis-à-vis input parameters and dump slopes is also explained.

Chapter 7 depicts the accuracy of the proposed stability analysis method based on the analysis of a few selected existing and planned dump slopes in different mines.

Chapter 8 discusses the significant outcomes of the thesis and their mechanism.

Chapter 9 assimilates the significant findings and essence of the thesis. It also states the limitations and the scope for future work.