International Journal of Rock Mechanics & Mining Sciences 82 (2016) 71–82

Contents lists available at ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

journal homepage: www.elsevier.com/locate/ijrmms

A stability-economic model for an open stope to prevent dilution using the ore-skin design

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A R T I C L E I N F O

Article history:
Received 10 May 2015
Received in revised form
26 November 2015
Accepted 22 December 2015
Available online 4 January 2016

Keywords:
Ore-skin
Stope design
Discrete Fracture Network (DFN)
Sloughage
Dilution

A B S T R A C T

In this study, the ore-skin design approach is presented in the context of a hypothetical open stope mine. A stability-economic model was developed to estimate the ore-skin thickness that can be left unmined to maintain the integrity of an open stope and control excessive ore dilition from hangingwall sloughage. The first stage of the approach consists of performing a cost-profit analysis to determine an economic break-even ore-skin thickness. The second stage includes using discrete element numerical methods to evaluate the stability of a certain ore-skin thickness. Two numerical methods were employed for this assessment, including a discrete fracture network (DFN) method and a hybrid discrete element / discrete fracture network model. Results indicated that the minimum ore-skin thickness required depends on the quality of governed rock mass and can be a function of stope lifetime.

1. Introduction

Open stoping is a bulk underground mining method mostly used in presence of a steeply dipping ore-body which presents a relatively regular shape. The method involves the extraction of large blocks of ore called stopes. The opening of a stope requires a minimum of two developments: a top and bottom sill. Drilling and blasting of the stope is performed from the top sill, and the broken ore is then extracted from the bottom sill. The stope generally remains unsupported during the entire extraction process.

The main advantages of this mining method are that it is a non-entry method, making it one of the safest underground mining methods, and that it can achieve high production rates. Nevertheless, the operation of a large unsupported underground opening is often accompanied by instability issues that can lead to significant dilution rates. This can be problematic, since excessive dilution rates can result in the suspension or closure of a mine operation .[1–4]

The extraction of an underground open stope initiates a stress relaxation in the stope hangingwall that generally leads to the sloughage of the stope face. Sloughage represents unstable material, located outside the stope limits, which falls or slides into the stope. The waste material (i.e., material with metal content below the acceptable limit) is then extracted with the ore and enters the processing stream, causing increased dilution.

The effect of dilution on the economics of an open stope mining operation is well understood. In general, its impact on mine economics is based on the direct and indirect costs associated with the excavation, handling, and processing of the waste material. The direct costs of dilution include the cost of drilling, blasting, mucking, hauling, crushing, hoisting, milling, and treatment of the waste material. The indirect costs include delay in the stope cycle, increased volume of tailings, additional backfill material for the stope, etc. These costs can become significant when there is excessive ore dilution. As a result, the reduction of the cost of dilution has always been a significant challenge in underground mine projects.

Hangingwall (HW) sloughage has been identified as the dominant source of unplanned dilution in open stope underground mines.[5–7] In cases where the immediate HW consists of a weak or highly fractured rock mass, the HW sloughage, and consequently the ore dilution, can increase significantly, resulting in increased mining cost. In such case, adopting an appropriate and optimized HW sloughage control strategy is essential to ensure the economic viability of extracting the stope. The appropriate and optimized strategy is generally the one that offers the best economic outcome.

There are several HW sloughage control strategies. They can be categorized as using either reinforcing techniques or designing and planning approaches. In the presence of a weak HW material

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http://dx.doi.org/10.1016/j.ijrmms.2015.12.001
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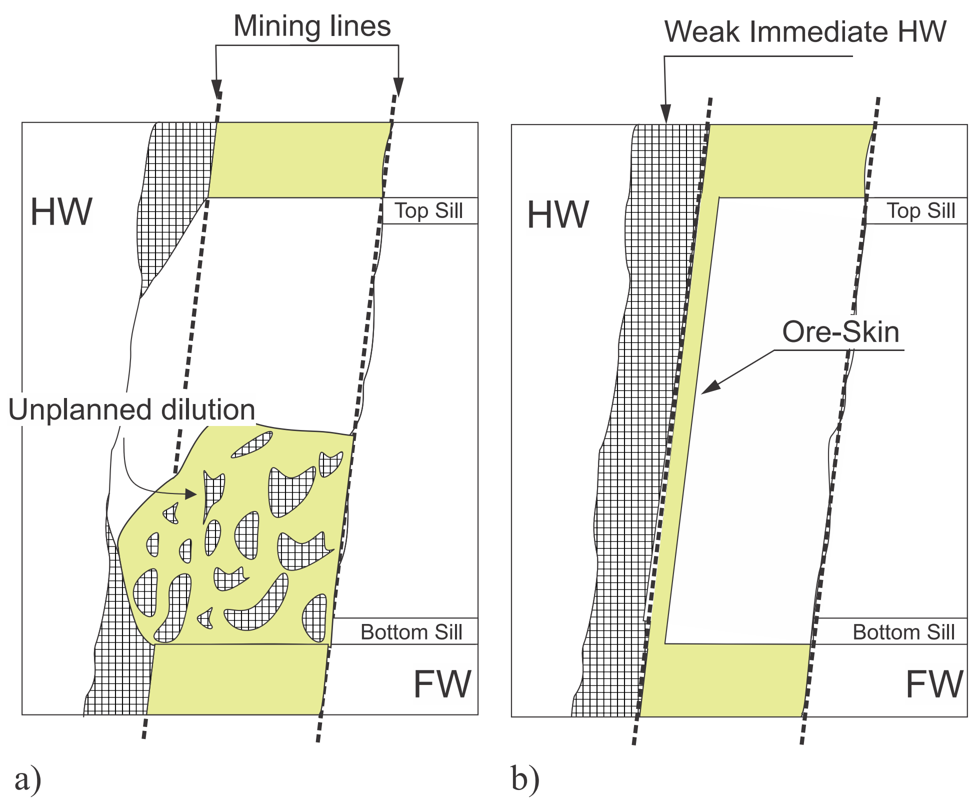

Fig. 1. Conceptual model of the ore-skin design method: (a) open stope without ore-skin; (b) open stope with ore-skin.

and a competent ore-body, the effectiveness of reinforcement system (such as cable bolts to retain the stability of HW) is very limited. Likewise, adopting the stope size (HW hydraulic radious) reduction strategy would not significantly influence the amount of sloughing material due to the poor quality of the rock mass. Additionally, designing smaller stopes requires more developments which further increase the mining costs.

An alternative design approach that allows achieving relatively large stopes while contending with weak HW is the “ore-skin” design, assuming the ore-body consists of a relatively competent material. The design requires leaving a certain thickness of ore unmined (i.e., an ore-skin) to support the weak adjacent or overlying HW, preventing HW sloughage (Fig. 1). The ore-skin design has already been implemented in different mining operations around the world and was shown to be successful at achieving reduced dilution rate .[8–10]

By leaving an appropriate thickness of unmined ore along the HW, one can achieve reduced dilution rate; however, the mining recovery is also reduced. Nevertheless, this approach can offer the optimal economic outcome compared to other HW sloughage control strategies involving weak immediate HW and a competent ore-body. This necessitates an investigation of the effect of implementing the ore-skin design on the stability of the stope and on the resulting ore dilution.

This paper presents a two-stage approach developed for the design of an optimum ore-skin. The first stage determines the maximum ore-skin thickness that can be left unmined for which the economic profit generated by the ore-skin design is equal to the one generated by the typical stope design (i.e., the break-even OST). For this assessment, a cost-benefit analysis is used. The second stage determines the minimum geomechanically stable ore-skin thickness which can be left unmined to keep the non-economical material from entering the ore processing stream. For this assessment, numerical methods are used.

2. A case study of an open stope underground mine

To illustrate the proposed two-stage approach, this paper investigates a hypothetical Canadian open stope underground mine (modelled based on real case studies). A conceptual underground gold mine was considered. The ore deposit is assumed to be a large, low-to-medium-grade gold deposit within an assemblage of volcanic and metamorphic host rocks. Typical underground stope geometries and typical economic parameters are considered.

2.1. Stope geometry

Fig. 2 shows the stope dimensions for the case study as 20 m wide, 30 m high and 15 m long along strike (stope span size). Therefore, the hydraulic radius of the HW is 5 m, and the HW is dipping 70° to West. The weak HW zone is assumed to be a highly fractured graphite shale rock unit with an average thickness of 4 m. The stope is located at a moderate depth of 500 m below surface.

2.2. Economic parameters

The economic parameters introduced in Table 1 are considered in this study. These parameters are based on a typical 8000 t/day operation scenario in Canada. The total operating cost includes direct costs related to the opening, exploitation, and processing of a stope, such as drilling, blasting, mucking, hauling, crushing, hoisting, milling, treatment, as well as general and administrative costs. It should be noted that the indirect costs of dilution previously mentioned are not considered in this analysis because they are difficult to qualify.

2.3. Geomechanical properties

For simplification purposes, the properties of the host rock and