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International Journal of Rock Mechanics & Mining Sciences 44 (2007) 903–921
International Journal of Rock Mechanics and Mining Sciences
www.elsevier.com/locate/ijrmms

Slope geometry design as a means for controlling rockfalls in quarries

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Received 7 June 2006; received in revised form 26 January 2007; accepted 2 February 2007
Available online 23 March 2007

Abstract

This paper presents a rockfall control method for rock quarries, based on benched rock slope design and catch-bench width control. The aim is to prevent rockfalls in quarries, which cause a significant number of accidents and even fatalities. Whereas catch ditches have traditionally been used as the main rockfall control method for roads and highways, benches carved into slopes are typically used in open-pit mining. In the road engineering field a simple empirical technique, recently reviewed and updated, has long been in use that is capable of ensuring slope designs that prevent falling rocks from reaching the travelled area of a road. Such techniques are lacking in the quarrying field, however, and this work is an attempt to develop a method similar to those developed for road engineering, but specifically adapted to quarry slope geometries. Using statistically significant data on the parameters affecting falling block trajectories, obtained from empirical data and from a back-analysis performed using a rockfall modelling code, we estimated geometries for quarry slopes that would prevent falling rocks from reaching work areas. This information was compiled and presented in the form of charts (for 2-bench, 5-bench and 8-bench slopes) that enable the user to design rockfall-safe slopes.

Keywords: Rockfall; Quarrying; Catch-bench width; Rock slope design; Mining safety

1. Introduction

Rockfalls are a significant hazard in open-pit mining and quarrying (Fig. 1) and in road and highway rock cuts (Fig. 2). They are also a hazard in mountain areas or villages and towns with abrupt topography, where it is not usually economically feasible to stabilise all the areas that may be sources of rockfalls. The problem with rockfalls is that they may adversely affect people or machines in mining exploitations, vehicles using roads and highways, and even people inhabiting populated areas in mountainous regions [1,2].

Even if the costs associated with rockfalls are typically much lower than those associated with large-scale slope instabilities, the number of accidents and fatalities arising as a consequence of either tend to be more or less equal, as has been pointed out by a number of authors [3,4]. These observations seem to concord with data for quarries in Northwest Spain, where, in a study of mining accidents over an 18-year period in the province of Pontevedra, thirty accidents involving fatalities or severe injuries were recorded [5], five of which were slope related (three associated with general slope instability, and two with rockfalls). Thus, 43% of slope-related accidents were caused by rockfalls. Note that this number of slope-related accidents is not excessive, explained by the fact that most of the quarries were ornamental granite quarries, where low fracturing of the rock mass means that blocks do not tend to become detached and fall.

The situation is rather different, however, in exploitations based on more fractured rock masses. ANEFA, the Spanish Association of Aggregate Producers [6], reported that over 20% of accidents in these quarries were due to rockfalls, the most common single cause of fatalities (Fig. 3). These alarming data—thirty-five rockfall-related fatalities in Spain over a nine-year period—inspired this study.

In the early stages of development of rock-slope engineering, efforts were focused on analyses of rock, discontinuity and rock-mass properties, and slope stability. In mining, the main aim was to ensure the

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doi:10.1016/j.ijrmms.2007.02.001

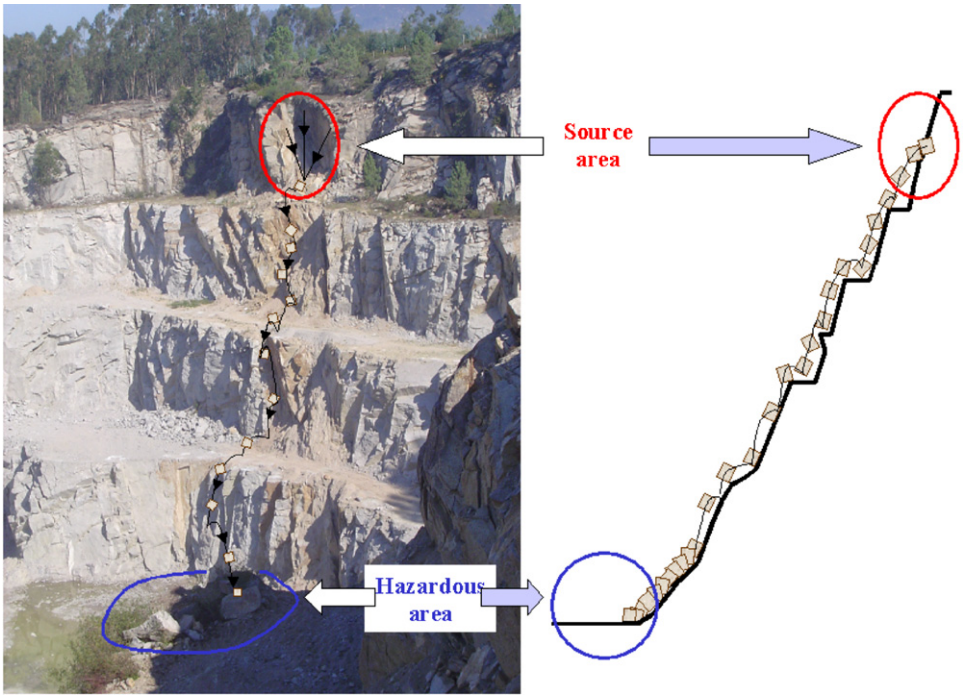

Fig. 1. Rockfall trajectory.

Fig. 2. Rockfall in late 2005 at a tunnel mouth in Northeast Spain resulting in one fatality [7].

stability of the general slope—an aim that was compatible with financial exploitation of the mineral. Ensuring bench stability usually implies very low dipping slopes, which generally renders mining non-profitable, and so general slope stability, rather than bench stability, is the goal.

With a view to developing accident prevention measures, in recent decades an interest has developed in the analysis of rocks that become detached from a rock mass, in terms of rock fall path, height, velocity, and energy. Apart from the software tools that have been developed to statistically estimate rockfall trajectories, empirical methods have also been applied to the identification and prioritisation of hazardous slopes.

The issue of rockfalls in open pit-mining has been analysed by a number of authors, who have proposed either simple estimate approaches, or more complex reliability-based methods aimed at maximising net profit [7–10]. The latter approach, however, is not suitable for quarry design.