International Journal of Rock Mechanics & Mining Sciences 56 (2012) 171–181

Contents lists available at SciVerse ScienceDirect

International Journal of Rock Mechanics & Mining Sciences

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

Experimental study on rockfall drapery systems for open pit highwalls

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ARTICLE INFO

Article history:
Received 23 March 2012
Received in revised form
12 July 2012
Accepted 27 July 2012
Available online 1 September 2012

Keywords:
Rockfall
In situ tests
Surface mine
Impact energy
Underground portals

ABSTRACT

This study presents in situ experiments carried out at an open cut mine in New South Wales (Australia). The research intends to improve the current knowledge on drapery systems for rockfall hazard management in mining environments. Blocks were released from the top of two different sections of the highwall: with and without a rockfall drapery system installed on the highwall. The trajectories of the blocks were recorded by using synchronised stereo pairs of high speed cameras. Velocities were derived from the trajectories and used to gather rockfall motion parameters (restitution coefficients) and various energies.

1. Introduction

Rockfall represents a significant safety hazard in mining environments around the world. It is the cause of serious injuries or fatalities to personnel and can damage infrastructure and machinery. Moreover, it can result in major financial losses when production is temporarily stopped for safety reasons. The hazard associated with rockfall events needs to be rigorously managed in both surface and underground operations. Indeed, a reliable approach for designing slopes, portals, roads and ramps depends critically on suitable rockfall protection systems.

Over the last three decades rockfall has been widely studied for roads and highways [1–4], but it is only recently that it has been accounted for in the context of open pits, quarries, [5–8] and underground mines [9,10]. Data collected from worldwide databases show that rockfall is one of the most serious causes of injury in mining operations [8,10–16] and several fatal events have been recorded since the mid 1990s.

Rockfall in underground mines is mainly related to roof or rib failure and inadequate examination/maintenance [10]. The situation is different in open pit mines, where rockfall is generally associated with geological features, weathering of the rock surfaces, blast-induced fracturing, and machinery activity on top of crests and along roads at the bottom of highwalls.

In open pit mining, rockfall has been the topic of a number of studies [17–19] which have proposed various approaches for safe and cost effective remediation solutions. These have resulted in different protective measures being suggested, either to prevent rockfall or to control its consequences. These measures include active systems designed to prevent instability (e.g. wire anchors, rock bolts) and passive systems that control the dynamic motion of the blocks (e.g. benches, catch ditches [20–21], flexible catch fences [22–28], attenuator systems [29–32]). Drapery systems [29], placed against the rock surface and combined with face bolting, fall within these two categories. They directly act on the stability of the blocks, but also control their fall should failure occur. Such systems are common practice within Australian open cut mines.

In surface mining, draperies are used to prevent rocks from impacting directly onto the concrete culverts used as portal structures for underground access. However, blocks can still fall under the net and land on top of the portals and/or in their vicinity. This represents a serious hazard for highly-worked areas at the bottom of the highwalls, and a proper prediction of the block trajectories and velocities is of prime importance in assessing and mapping the residual rockfall hazard.

Even though drapery systems have been used for several years as a rockfall protective measure, it is only recently that their design and field-testing have been addressed in the scientific literature. In particular, [33] and [34] compared the performance of hexagonal wire mesh, ring nets and cable net drapery systems

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http://dx.doi.org/10.1016/j.ijrmms.2012.07.030

used for slope protection along North American state highways. The performance of wire mesh and cable net systems were also numerically investigated by [35], where a finite element model was calibrated from the experimental results in [33] to better understand the influence of mesh weight, the friction interface between the rock and the mesh, and the accumulation of debris on the system behaviour. The study in [29] developed a full scale test procedure to evaluate the behaviour of different types of drapery mesh panels, and $6\ \text{m} \times 6\ \text{m}$ wire meshes or cable net panels connected to a rock mass were tested under a force of 200 kN using an hydraulic jack. These results showed the need for a better understanding of the overall behaviour of the drapery system, with a specific focus on the design procedures and installation methods. However, as far as the authors are aware, results for rockfall tests involving drapery systems have been rarely addressed in the scientific literature [31].

For the first time, full-scale tests of rockfall impacting on drapery in a surface mine have been performed and the results are presented in this paper. The experiments were carried out at an open cut mine in New South Wales (Australia) and recorded by using synchronised stereo pair high speed cameras. Two series of tests were performed at two different locations and compared: one with drapery on the highwall and one without. Three-dimensional (3D) block trajectories were reconstructed by using stereo-photogrammetry, which has seldom been used for rockfalls [36,37]. Block velocities were measured and used to infer the restitution coefficients and the impact energy on the portals.

The study, funded by the Australian Coal Association Research Program (ACARP), was carried out with the objective of improving the current knowledge on drapery systems for rockfall hazard management in mining environments and to assess the residual hazard. Important information on the type of motion, trajectory, arrest zones and potential impacting energy were gathered and observations for protection system optimisation were collected. These data are crucial for the safe and effective design of portals and roads in open cut mines.

2. Experimental testing

2.1. Experimental site

Two series of full scale rockfall tests were carried out at the Beltana mine (owned by Xstrata Coal), one of the most productive longwall thermal coal mines in Australia, located in the Hunter Valley in New South Wales (Australia) near Singleton.

Beltana longwall operations commenced in 2003, with the construction of portals to provide an entrance to the underground long wall for workers and machinery, as well as access for electricity, ventilation air, water, communication systems and coal conveyors. In 2004, a rockfall control system was installed to minimise the risk of falling blocks and to protect personnel and equipment working at the base of the wall. The system, placed over the highwall on top of each portal, consisted of four mesh strips of flexible draping (a double twist type from Maccaferri Pty Ltd). The strips, each 4 m wide, were clamped together along their long edges, anchored at regular intervals at the top of the highwall 5 m behind the crest, and restrained by a single cable, threaded through the bottom edge of the drape and anchored at each tend. The drapery was combined with rock bolts drilled into the face to stabilise parts of the highwall.

The global height of the highwall varies between 40 m and 50 m and its slope is around 70°. Two testing sites were chosen around three portal entries at the south-eastern end of the highwall (Fig. 1a) over a length of 200 m where mining operations are no longer occurring. In consequence, the experimental programme was conducted without affecting mine operations or exposing mine personnel to any risk.

The first site (Fig. 1b), referred to as "Site 1—drapery", was located in correspondence to the first portal, where the highwall is 39 m high from the top of the portal and a drapery system is installed on the rock surface. The drapery, after more than six years of use, is still in good condition without evidence of serious damage along his length or near the clamping connecting the 4 strips of mesh. Two berms are located at the bottom of the highwall at 10 and 15 m from the base of the highwall. The second testing site (Fig. 1c), referred to as "Site 2—no drapery", is located 207 m North-West of "Site 1—drapery", in front of a large mud-filled depression. No rockfall protection system is installed on this part of the highwall. The location of the second site was mainly driven by safety considerations. Indeed, the mud depression was used as a capture area for the blocks.

For the purpose of the study, a simplified geological profile of the two sections has been considered in which seven different layers of material were identified. The top of the highwall, referred to as the Denman formation [38], was subdivided into three main layers: sandstone, mudstone and mudstone-debris. The latter were located at the bottom of the previous layer. A thin layer of coal was identified in the middle of the highwall immediately underneath the Denman formation, followed by a succession of interbedded layers of sandstone and mudstone and then mudstone and siltstone. A layer of massive sandstone was identified again at the bottom of the highwall. In both sites, a substantial amount of debris was located on top of the portal for "Site 1—drapery" and above the mud depression in "Site 2—no drapery".

A detailed geostructural survey of the highwall was performed in [39]. The in situ block size distribution of unstable blocks was also carried out and reported in [40].

2.2. Testing set up

Thirteen concrete blocks whose shapes were in accordance with EOTA [41] were cast in the Laboratory of the Centre for Geotechnical and Materials Modelling at the University of Newcastle. The block size, about 30 cm in the largest dimension, was chosen on the basis of data related to previous rockfall events [39]. The blocks weighed 44.5 kg.

All blocks were painted in yellow with a unique black pattern on each of the six square faces in order to determine their rotational movement during the fall (Fig. 2a). A 60 t crane with a man basket was positioned at the top of the highwall adjacent to the testing sections and used to release the blocks (Fig. 2b). A detailed inspection of the mesh was carried out on site 1 before testing and a suitable location was identified to insert the blocks under the net. This was achieved by cutting a few diamonds in the mesh without damaging the entire strip. Note that the blocks were not recovered after the tests for safety reasons.

The objective of the study was to record and reconstruct the motion of each block using stereo-photogrammetry. As far as the authors are aware, this technique has only used before in [36]. Two sets of stereo-pair video cameras were used, where each set covered about 30 m of the highwall. The first set of stereo-pair cameras (Canon EOS 7D, 60 fps, 720×1280 pixel, 45 mm focal length) captured the top of the highwall whereas the second set (Optronics CR600, 500 fps, 1024×1080 pixel, 35 mm focal length) was used for the bottom section of the highwall. The two camera pairs had an overlap of about 10 m along the highwall height [42], allowing the recording of the full fall of the block from the starting point to the bottom of the highwall. Unlike the set up used by [36], each pair of cameras was synchronised, which reduced the error in capturing the motion.