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Stability Investigation of Open-Pit Slopes During Blasting Activities

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***Abstract*:- In open pit mines, blasting activity is one of the major factors affecting slope stability. Blast-induced energy can create a wide range of movement, from minor slope deformations, such as rockfall, to major slope changes, including slope failures. The aim of this study was to investigate various slope responses to the blast by using 15 case studies of real blasting activity in different mines around the world. New technology was also used for the first time to detect small slope movements by measuring ground luminance changes using visual data captured by a high-quality drone camera. Stability assessment of open pit slopes affected by blast-induced energy are discussed in this paper and the results of different slope behaviors, based on the slope's location in relation to blast patterns are provided.**

Keywords: Blasting; Slope Failure; Mining; BlastVision®; GroundProbe; Slope Stability; Wall Control

1. INTRODUCTION

Slope design significantly affects the safety and economics of mining operations. Although steeper slope angles may cause geomechanical instabilities [1], they improve the cash flow and profitability of a project. The ideal slope design, in which safety is maximized, and costs are minimized, will lead to failure after mining activity ceases. However, in many open-pit mines, slope failures occur when the pit is still active and mining production is in progress. Such geotechnical risks have given rise to many investigations on factors contributing to slope failure.

The factors that contribute to slope failures are slope dimension, geological structures, physical and mechanical properties of slope material, and the external forces acting on the slope [2]. These parameters are divided into two categories. The first group is independent of engineering and is site-specific such as the geology of the area, geological structures, water seepage, etc. The second group, on the other hand, is not independent and is managed and controlled by engineers. This type of factor should be designed to have the minimum negative impact on slope stability. An example of such significant and controllable parameters is blasting.

If not designed well, a considerable amount of the blast energy will be released in the form of ground vibration and air blast [3]. This undesirable blast-induced energy can damage the slope immediately during the blast or after the blast takes place. As such, it is very important to monitor the slopes during the blast and to evaluate blast efficacy based on its impact on the slopes in the vicinity of the blast. Since the main aim of blasting is to facilitate production, with easy extraction and suitably sized material for feeding the mine crusher. However, most of the studies about blast performance evaluations focus on blast fragmentation size distribution, rather than slope behavior during the blast [4, 5, 6, 7]. The dominant type of monitoring equipment used is slope stability radars, which are not sensitive to detect small changes, such as rockfalls and minor raveling.

Another type of monitoring equipment that is used to capture blasting and slope responses is drones. This technology is common in open pit mines and low in cost compared to the traditional monitoring methods. However, drones cannot detect minor slope deformations due to the considerable distance between the drone and a blast pattern as well as the limited resolution of the optical sensors (for example, video cameras) used. Therefore, a better monitoring system is needed to detect accurate slope responses during blasts.

In general, safety and geotechnical risk assessment call for improved monitoring of slope behavior during blasting. This study investigates a new technology developed by GroundProbe, called BlastVision®, which uses a high-resolution drone-mounted camera and transforms visual video data into milliseconds of luminance changes on the ground. This highly accurate technique can be used on its own, or in conjunction with slope stability radars to gain a better overall geotechnical understanding of the slope behavior. Better monitoring of potential slope damage during the blast provides feedback for improved blast design and slope stability in the future.

2. MATERIALS AND METHODS

To analyze slope behavior in response to blasting, 15 videos of the blast activities near slopes were collected from various mines around the world. The videos start a few minutes before the blast initiation end and after the blast has been completed. The videos were taken by a drone-mounted camera. The location of the camera faced the slopes on 45-degree angle to cover the blast pattern and surrounding slopes.

The BlastVision® software was used to process the videos to enable a detailed geotechnical analysis of potential blast-induced slope damages. The videos were processed with this technology which detects different potential areas of interest at which considerable slope movements take place. Regarding BlastVision® analysis, there are some features, such as an amplified luminance detector and change in time that help reading millisecond slope changes induced by blast vibrations on the ground during the blast. An amplified luminance detector takes very small signals of movement based on the reflectivity of sunlight on the ground. Due to the high accuracy of these functionalities, very small movement changes such as rockfalls and raveling can also be observed and detected by BlastVision® technology. This paper shows examples where the technology has been successfully used to detect and identify areas of interest related to wall damage. Some examples are shown and discussed in the results section.

For each video several benches surrounding the blast pattern were observed the highly active areas that showed significant movement was observed by the BlastVision®, using the zoomed image views feature. The zoomed views feature helps detect small changes on the slopes that would not have been easily seen in the larger image or the unprocessed images. The zoomed view option increases movement detection accuracy. Among all the areas analyzed, that showed movement in each video, this paper discusses a few specific areas of interest that clearly indicated rockfall, raveling, or slope failures. These areas of interest were selected in different slope benches. For each area, some information including, the type of movement, the vertical distance of the area from blast pattern, and time of movement were gathered. Approximately three or four areas of interest were collected for each blasting video, creating 50 areas of interest in total.

After exporting the data, each area of interest is categorized based on the similarity of movement behavior indicated during the blast. For example, the areas that showed rockfalls only, without major raveling or slope failures, were grouped together and created into one category. For this analysis, all 50 areas of interest were divided into different groups based on their behavior and reaction to the blasts.

RESULTS AND DISCUSSIONS

Table 1. illustrates grouping areas of interest based on their behavior which created five different categories, meaning the slopes surrounding the blast patterns tended to have five different reactions during the blasting. The investigation shows that all the wall movements occurred specifically during the blasting time and no major movement was detected within 2 minutes after the blast was completed. In another word, from a geomechanically perspective, no major slope deformation will be expected after the 2 minutes after the blast occurred. Also, depending on the location of the slopes and their distance from the blast pattern, slope responses to the blast were different. As can be seen in Table 1, slopes that are on the same level as the blast pattern are divided into two groups based on rockfall behavior. It shows that major rockfall behavior comes with slope failure. Also, most of the walls which are located two to three benches above the blast pattern tend to react in only two different ways. Finally, the lower bench showed only one type of response during the blasting time. All the responses took place during the blast, and no major response was detected after the blasting activity.

Table 1: Different Slope Reactions based on their location in 15 case studies

Bench Location	Group	Rock fall	Raveling	Slope Failure
Wall above the blasting	1	Yes	Very Minor	Yes
	2	Yes	Yes	No
Walls at the same level of blasting	3	Yes	Yes	Yes
	4	Minor	Yes	No
Walls below the blasting	5	Very Minor	Yes	No

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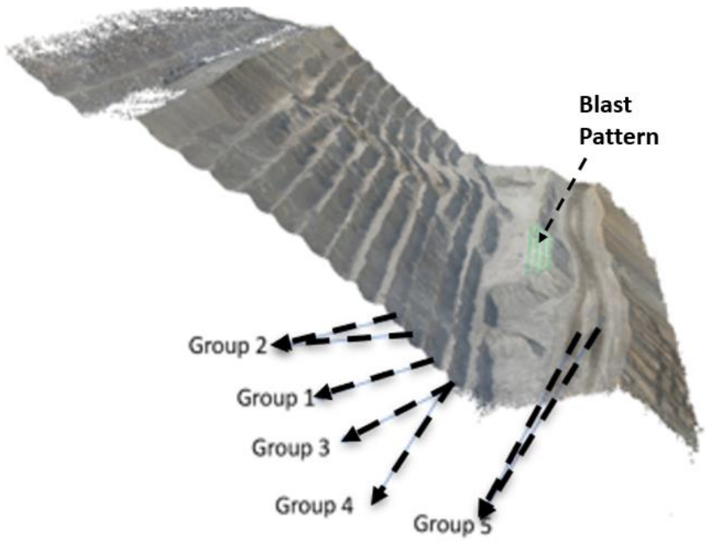

Figure 1. shows an arbitrary slope and blast pattern for an open pit mine. This image is used to illustrate the different reaction group location described in Table 1.

3.1 Group 1: Intact Rock Failure:

The first slope reaction that is detected during the blasting time is intact rock failure. This rapid process occurs during the blasts when the rock units are surrounded by non-persistent joints. In a recent paper by Bastola et al., [8], structural discontinuities are discussed as important to understand as they define the stability of slopes since they are the rock mass' weakest component. Depending on the type and size of the joints, geology of the area, distance from blast pattern, and even low blast vibration energy can cause intact rock failure. With the use of BlastVision®, this study has found intact rock failures occurred mostly on the wall that is one level above the blast pattern. The results of this study show that the probability of this occurrence rises when the highly jointed block is located on the upper side of the slope surface. Figure 2 shows an example of this wall response, provided by BlastVision® technology.

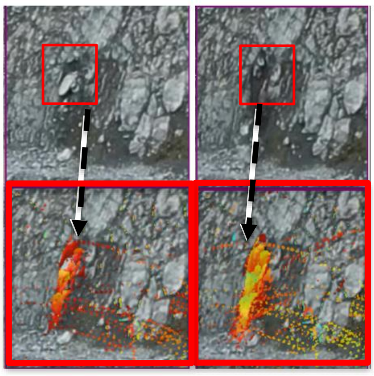

Figure 2. An example of a rock fall surrounded by discontinuities that failed during the blast. The right side of the picture was taken at the beginning of the blast and the left side was taken during this intact rock failure. Change in time visualizations is provided by BlastVision® on lower figure.

3.2 Group 2: Minor to Single Rockfall:

In addition to intact rock failure, normal rockfalls from slopes during the blast are detected by BlastVision® technology. Rapid speed and suddenness as well as the randomness of rockfalls make rockfall prediction difficult [9]. However, the results of this investigation show that this type of slope response usually occurs from the walls that are located 3 or 4 benches above the blast pattern. These rockfalls usually come with moderate to major raveling since they hit the slope surface on their way to the toe of the slope. An example of this category of rockfall is shown in Figure 3. in open-pit mining, catch bench are designed to predominately stop the flow of these types of rockfalls.

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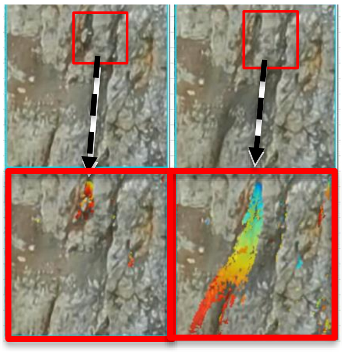

Figure 3. Visualization of rockfalls and the raveling detected by BlastVision® technology helps accurate analysis of slope response to the blast-induced vibration energy.

3.3 Group 3: Slope Failures:

Slope failure is the most unsafe reaction of a wall during blasting "large open pit guidelines and industry standards accept up to 30% of benches in open pits to collapse provided that they are controlled and that no personnel is at risk" [10]. There are some situations that raise the occurrence probability of slope failures during the blasting time. For example, in a double benching procedure, which stacks two standard bench heights, and has excavations without any catch bench at the toe of the first bench [11], the blasting pattern is usually designed with a minimum distance from the toe of the slopes. Decreasing the minimum distance between the blast pattern and slopes decreases the impact of blast vibration energy on slopes. Under these conditions, it is highly recommended to use pre-split blasting to prevent major slope damages, specially angled pre-splits, which result in less cress damage [12]. Other research [13] has proven that pre-split blasting plays a significant role in blast casting shock absorption. Also, in most cases where the blast is not appropriately designed, or pre-splits have not been used to minimize the blast-induced energy, slope failure tends to occur. It means the vibration energy impacts the wall significantly and creates big cracks on the crests of the wall located at the same level of the blast. An example is shown in Figure 4, left picture, where huge crest cracks appear immediately, and slope failure is initiated. Sometimes, after the failure occurs, the failed surface of the slope is still unstable and shows raveling. This continuous raveling can result in a second slope failure, which can also mean losing upper-level catch benches. Under these conditions, rock falls from upper slopes can reach the active level of the mine since there is no effective catch bench. This creates very hazardous and unsafe conditions. This study suggested that this type of slope failure is most likely to happen in the walls at the same level of the blast pattern.

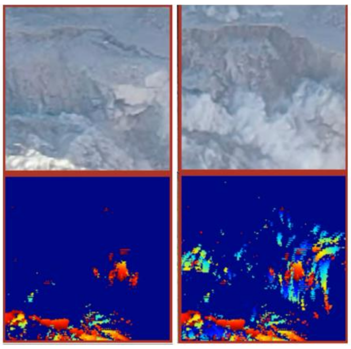

Figure 4. Visualization of cracking crests due to high blast-induced vibration energy that results in slope failure.

3.4 Group 4: Severe Slope Raveling:

As discussed in section 3.3, when the blast pattern is not designed appropriately, blast-induced energy impacts the wall directly. If the vibration energy is not intense enough to cause a slope failure, it impacts slopes negatively by creating severe large-scale slope raveling events. Figure 5 shows an example of a severe unraveling event using the change in time visualization from the BlastVision® application. In this example, the unraveling is caused by the blasting activity near slopes. It illustrates that blast vibration creates raveling for almost the entire wall near the blast.

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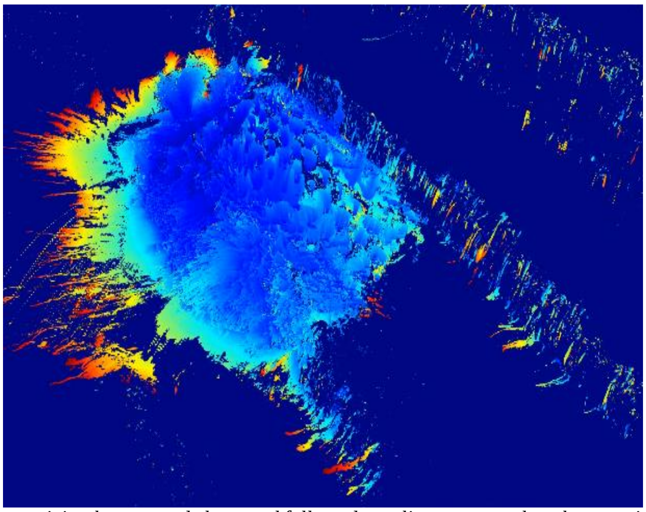

Figure5. Visualization of blasting activity that created slope rockfalls and raveling on upper benches provided by BlastVision® technology.

4.4 Case 5: Minor Raveling:

Minor raveling is another reaction category of a slope during the blasting time. Raveling can be created directly from blast-induced vibration energy or from rock falling and hitting the slope from higher bench levels. The analysis conducted for this research paper, using BlastVision® and 50 areas illustrates that this type of raveling created by vibration energy is the dominant slope response for the walls which are located below the blast pattern. Figure 6 shows an example of a minor raveling event that was detected with the help of the BlastVision® analysis software.

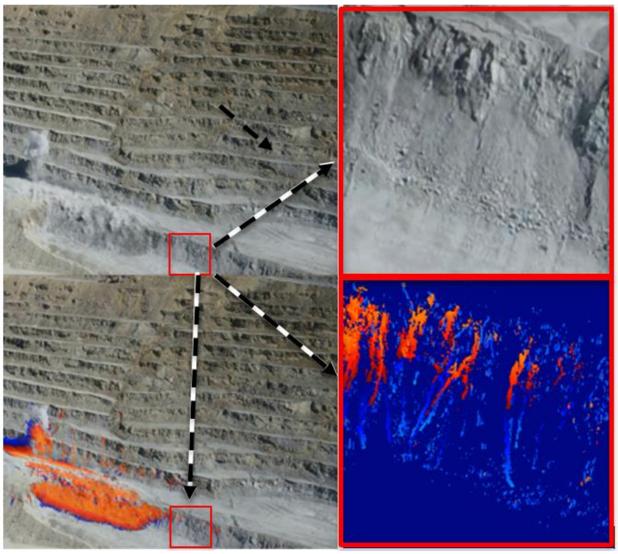

Figure 6. visualization of blasting in tiled image provided by GroundProbe showing location of raveling in area shown in green.

In addition to the mentioned wall's locations, the areas that had failed before the blasting occurred, were observed, and analyzed by BlastVision® technology. The results show that during the blasting activity, they mostly remain stable with very minor to no evidence of raveling and rockfall.

4. CONCLUSION:

This research has been focused on different types of slope reactions with regards to their locations to blast patterns during the blast. BlastVision® technology was used for the determination of slope movements in high-resolution frames. Blasting videos taken by the drone-mounted camera are processed. The visual data are transformed into temporal luminance changes by a new technology called BlastVision®. This process leads to improved detection of small slope movements at pixel level such as rockfalls, which are blind to be detected by most monitoring equipment.

The results show that when the blasting is not designed appropriately, the blast-induced vibration energy can negatively impact the slopes. These effects are different depending on many conditions and parameters including their distance to the blast pattern. This investigation shows that usually, the wall at the same level of the blast pattern is likely to behave aggressively in the form of slope failure and severe large-scale raveling. Also, the benches which are 2 or 3 levels above the blast patterns are likely to react

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in the form of major raveling, or as an intact rock failure, if they are highly fractured. Additionally, the benches below the blast pattern only show minor raveling. Finally, the locations of failed slope materials did not indicate any major movement during the blasting.

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