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Road and Rail Infrastructure III

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METHODS OF SURVEYING IN ROCKFALL PROTECTION

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Abstract

Rockfalls are common in the countries with significant amount of mountain area. It is estimated that 27 percent of the world's land surface are mountains and about 12 percent of the world's population lives in the mountains. Due to that fact, there is a need of constructing new roads and railways along mountain slopes. In those areas, rockfalls can cause serious damage to infrastructure with possible human losses. Ensuring rockfall stability is a major safety goal along railways and highways. In order to simplify the complicated equations involved in rockfall modeling, computer simulation programs have been developed, both in two-dimensional and three-dimensional domains. The analysis of rockfalls includes estimation of trajectories of the boulders that falls from specific height along the slope. Once movement of the rock has been initiated, its falling behaviour is controlled by slope geometry, slope properties and boulder properties. The geometry of the slope represents one of the most important parameters and therefore it has to be accurately measured and determined as an input parameter for calculations of rockfall stability. Two-dimensional simulations require slope profile divided into several segments along slope, while the three-dimensional simulations require dense and accurate data in the form of digital terrain model. In this paper available methods for determining the geometry of slope are presented. Advantages and disadvantages of each method are discussed taking into account how it affects the final result of rockfall analysis.

Keywords: rockfall stability, photogrammetry, laser scanning, total station

1 Introduction

Croatia's transport infrastructure network plays significant role in the European network, as it is located at the crossroads of transit routes between western and south-eastern Europe and between the central Europe and the Mediterranean. The territory of the Republic of Croatia is crossed by three traffic corridors, Pan – European traffic corridors V, X and VII.
52 % of Croatian land surface, or almost whole coastal and mountainous regions of Croatia, is situated in karst. Karst is specific type of terrain mostly covered by barren limestone or dolomite, easily soluble rock characterized by strong karstification formation– progressive mechanical, physical and chemical disintegration of karstic rock, which leads to widening of joints system in rock mass. Together with weathering of exposed rock on the slopes, it can create systems of blocks, which can easily cause rockfalls under certain triggering situation. Triggers are usually weather conditions, in most cases intense precipitation or extreme temperature highs [1].
Croatian karst regions typically belong to medium scale surface karst (Dinaric region, Alps, Pyrenees, Appalachian Mountains, Australian Mountains, etc.), which stand out due to their thick (up to 8 km) carbonate Mesozoic and Paleozoic sediments with the pronounced tectonic fragmentation equally affecting the occurence of horizontal and vertical (speleological) formations. Croatian karst extends from Slovenia in the northwest to Montenegro in the southeast with its northern boundary running south from the city of Karlovac towards the east passing into Bosnia and Herzegovina [2].

The vast majority of sections of Croatian Highways A1, A6 and A7, in total 570 km of length, are situated in the hilly karst terrain with numerous slopes cut in the karstic rock. Even worse situation is on over 2200 km of National roads situated on the same terrain, where the slopes are steeper, older (and subsequently more weathered), closer to the road and less protected, owing to less strict demands for construction. In addition, many urbanized areas are situated directly under natural or man-made slopes, such as Opatija Riviera, city of Omiš and Makarska Riviera. In the last several years, a number of rockfalls was documented to have occurred in the mentioned highways, roads and urbanized areas [3].
Current approaches to the analysis of rockfalls require knowledge of the geometrical, structural mechanical properties of slopes, as well as boulder properties. The mechanical properties of rock slope material and boulder properties can be derived from in-situ and laboratory tests, whereas the geometrical characteristics only come from the field measurements.
The inaccessibility of steep rock slopes does not allow direct measurement of slope surfaces and collecting structural properties by traditional methods. Breaking point in slope geometry data acquisition system have come in the past several years, when some new measuring methods and techniques have become more available such as laser scanning and digital photogrammetry.

2 Total-station measurements

Total-station enables to measure heights, distance and angles to provide accurate positioning data. Total-station measurement depends greatly on the skills of the operator in terms of both capturing a sufficient number of points and selecting suitable points to represent the surface of the rock or slope. It is usually used for the purpose of two-dimensional simulations of rockfalls, when the slope profile is divided into several segments along the observed route. Rockfall simulations are carried out for each segment. Protection measures against rockfalls are designed according to the most critical segment. A major disadvantage of this approach is that the lateral dispersion of rock boulders is not taken into account. It doesn't provide sufficient amount of information required for rock fall analysis and can sometimes lead to an improper solution. An example is given in Figure 1.

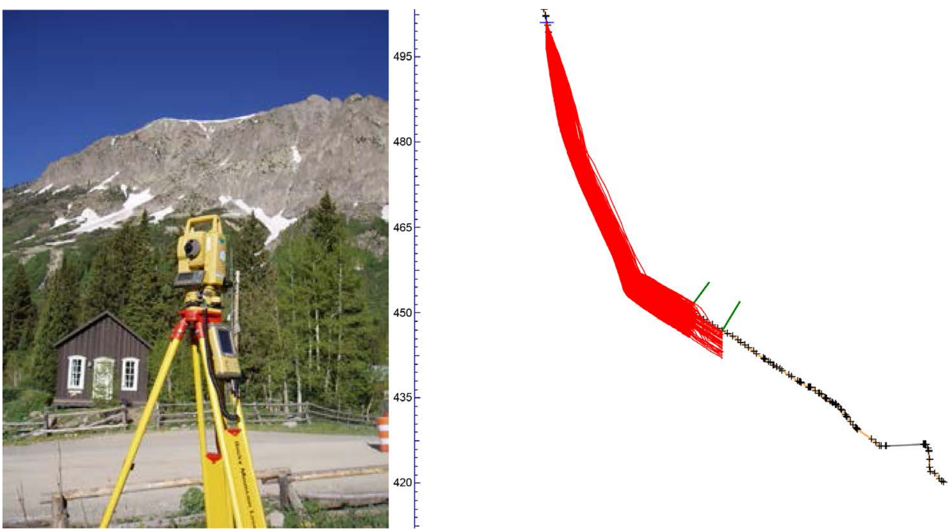

Figure 1 Typical total station equipment [5] on the left; Example of representative profile for rockfall analysis for the Stupica location on the state road D512 Makarska-Vrgorac [4] on the right

The rockfall protection barriers are calculated for the Stupica location on the state road D512 Makarska-Vrgorac in The Republic of Croatia. Stupica slope was divided into several representative profiles and two protection barriers were chosen according to the most critical slope [4]. Total station measurements are still usual method for obtaining geometrical characteristics of the rock slope for the rockfall stability analyses in Croatia. Structural properties of slopes and information about boulders' volumes are being collected by such traditional methods which can often take a lot of time.

3 Laser Scanning

Laser scanning or "3D laser scanning" is also known as ground based LiDAR which stands for "Light Detection and Ranging" system. LiDAR is an emerging three dimensional mapping technology that employs a laser and a rotating mirror or housing to rapidly scan and make image volumes of surficial areas such as: rock slopes and outcrops, buildings, bridges and other natural and man-made objects [6]. First it appeared in 1990's and to these days is becoming more and more popular in different fields.

There are two LiDAR types depending on the position of measuring equipment: – 1.terrestrial or ground based LiDAR (TLS), which refers to the tripod-based measurements and 2.airborne LiDAR (ALS), which refers to measurements made in the air by using a helicopter or an airplane. 3D laser scanners work by emitting immense number of laser beams to chosen surface and recording the reflection of the beam in order to accurately determine the distance to the reflected object (Figure 2).

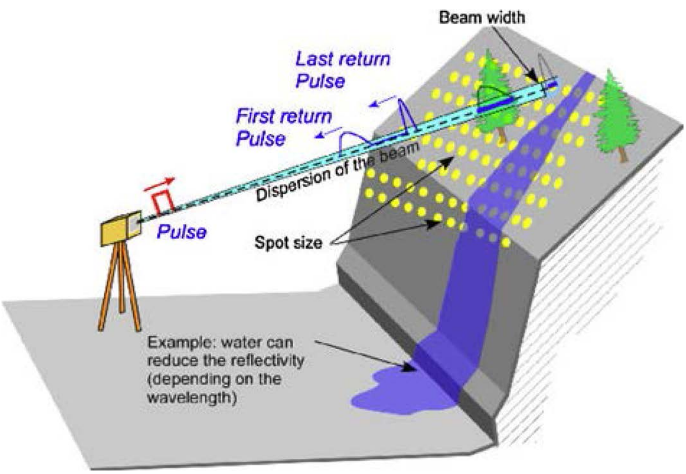

Figure 2 Principles of laser scanning for terrestrial lasser scanner (TLS) [7]

In this way 3D point cloud is created which represents an image of the rock slope face. The rotating mirrors or rotation of the housing allows millions of measurements to be made in just a few minutes which depend on the type of the scanner. Immediately after one pulse is received and measured, the scanner transmits another optical pulse slightly horizontal (or vertical – depending on the scanner) to the previous pulse using a rotating mirror or rotation of the housing. This process is repeated thousands of times per second, thus generating distance values for millions of points on a reflected slope. From the distance and the orientation of the laser pulse, the xyz coordinates associated with each reflected pulse can be determined. In addition, the intensity of the returned pulse is determined. In general, light coloured objects and closer objects give a higher reflection compared with darker objects and objects farther away. Together, the xyz coordinates and associated intensity values for millions of data points outputted by the laser make up the “point cloud” [6, 8]. Point cloud is the basic output from a 3D laser scanner. The most generic point cloud file format is a 3D coordinate file. The point clouds are then processed to extract geotechnical information, which includes discontinuity orientation, length, spacing, roughness, and block size. The first step in point cloud processing is to orient the point cloud into the real world coordinate system, based on data taken in the field. Most of the laser scanners are also equipped with high-resolution cameras, thus providing digital images of the scanned slope which can be draped onto the point cloud to provide a 3D colour digital terrain model, DTM. An example of a DTM from LiDAR measurements is shown in Figure 2. The main advantages of this technology are high accuracy, high resolution (mm to cm order) and very high data acquisition speed [8].

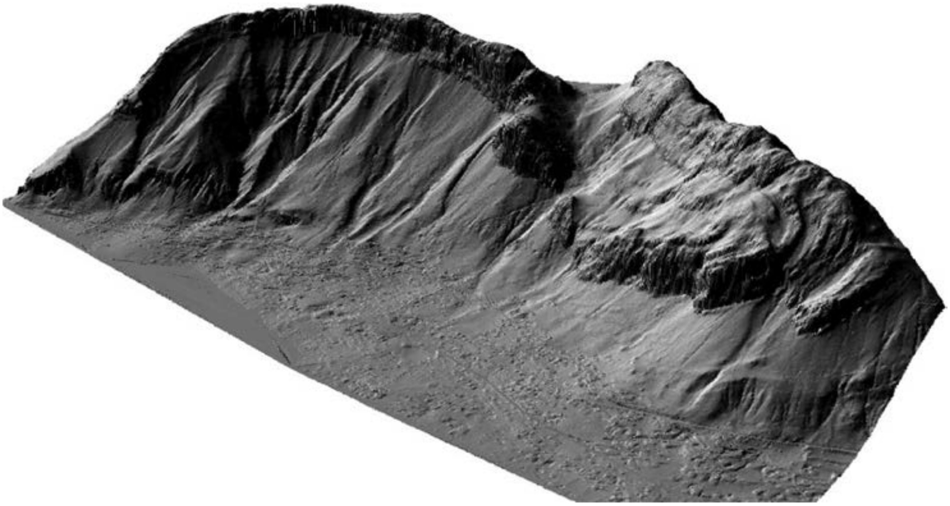

Figure 3 Digital terrain model (DTM) based on laser scanning, Veyrier-du-Lac, France [9]

According to Jaboyedoff [7], the application of laser scaning in rockfall engineering can be divided into four types: detection and characterization of rockfalls, hazard assessment and susceptibility, rockfall modelling and rockfall monitoring. To detect and characterize rockfalls, precise maps of surface need to be collected. Airborne LiDAR (ALS) has shown as a good tool for precise mapping of a large area, but still it is an extremely costly technique. It enables doing structural analysis at regional scale without entering the dangerous zone beneath a slope in a much faster and safer way, compared to the traditional methods. It is also very useful for hazard assessment since it enables to determine input parameters for rockfall hazard rating systems, such as: joint orientation and boulder volumes. It enables to accurately estimate volumes and positions of unstable boulders as input parameter for any rockfalls trajectory simulation, which enables to determine the influence area. Also, by repetitive measurement of rock slope face, 3D images are compared to previous images with precise incremental movements to cover big area of slope face, and not just one block, can be obtained in due time, by usage of an available software.

4 Digital photogrammetry

Photogrammetry is an optical method which allows to determine the geometric properties of objects to metrically reconstruct them by means of measuring and interpreting photographic images, using Image-based Modelling (IBM) [10].

There are two types of photogrammetry, depending on the position of the measuring equipment – 1. terrestrial, which refers to terrestrial photogrammetry and it refers to measurements from a fixed terrestrial location and 2.aerial photogrammetry, which refers to measurement made from an aircraft and is usually oriented vertically to the ground. Figure 4 shows a basic principle of photogrammetry. The 3D coordinates of a slope are determined from digital images taken of the same slope from different directions. It is necessary to collect at least two images of a slope, since the 3D coordinates are determined from at least two corresponding rays which are defined by perspective centre and each image point, showing spatial direction to the corresponding object point [9]. The advantage compared to LiDAR is that it directly provides colour image which enables to create textured 3D model.

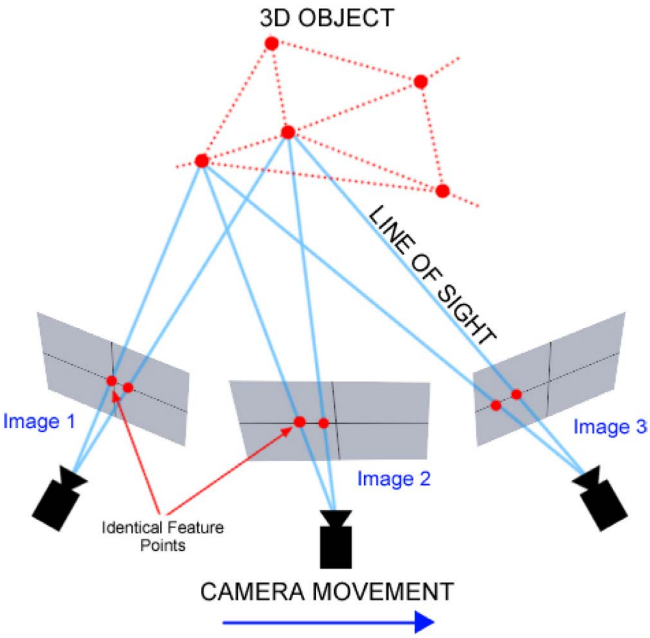

Figure 4 Basic principle of photogrammetry [11]

The equipment includes high resolution digital cameras, a tripod and markers which need to be attached to the slope as reference points. It is relatively inexpensive equipment, easy to handle which enables to take a large number of photographs in a short time. In terms of cost, photogrammetry equipment is less expensive than LiDAR, but photogrammetry softwares can sometimes be very expensive depending on data that need to be collected by such method. Today, there is a large number of photogrammetry software which are designed for extracting structural properties of the slopes such as number of trays and orientations of discontinuities. Those parameters also are basic input parameter in most of the rockfall hazard rating systems. Also, by comparing images taken in different times, displacement and deformations can be detected.

It must be emphasized that the advantage of LiDAR, as opposed to photogrammetry, is in scanning a slope that has vegetation. LiDAR light can penetrate through small openings between the slope and its vegetation to provide information of the rock underneath. On the other hand, obtaining a good result of photogrammetry depends on the available natural light available behind vegetation as it is affected by changes in light in different directions due to basic principle of photogrammetry to take multiple images of the same scene from different locations.

5 Conclusion

The traditional and new techniques in rock slope geometry data acquisition methods are described in previous chapters. Traditional total station measurements are very widespread in Croatia, though it doesn't provide sufficient amount of information to do for rock slope stability and rockfall analyses. In terms of cost, it still represents the lowest cost, but with major limitations. In the recent years, laser scanning and photogrammetry has become more and more popular in rockfall and rock slope stability applications in the whole Europe starting from Italy to France and Spain. There are different types of applications for each technique, from rockfall identification, modelling and monitoring. Even though both techniques are based on different principles, both produce a high-resolution 3D image of the analysed area. Obtaining the same amount of informations using total station would be highly impractical.
In terms of accuracy, compared to traditional method, both LiDAR and photogrammetry are suitable for rockfall stability analyses. It's believed that both of these methods provide accurate digital terrain models needed for the numerical analyses, as well as enough and accurate data with sufficient amount of information to do structural analyse for the rockfall hazard rating systems.

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