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Mapping of a rockfall site with an unmanned aerial vehicle

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ABSTRACT

The combination of geological, topographical and climatic conditions causes mass movements. Rockfall, which is a frequently seen disaster at mountainous regions, gives damage to residential areas and transportation corridors. Rockfall barriers are being designed to capture falling rocks worldwide. The classical method applied in rockfall analysis is 3D modelling of the study area to determine rockfall trajectory with the help of Digital surface model (DSM). 3D rockfall simulation is performed in order to determine bounce height, maximum run-out distance and kinetic energy of rocks. DSM of the study area needs to be accurately determined to properly design barrier system. Unmanned aerial vehicle (UAV) can be used to prepare actual DSM from inaccessible areas. In this study, we prepared the DSM of the area which was affected from rockfall due to high rainfall with using a UAV.

1. INTRODUCTION

Turkey is frequently exposed to geological hazards, which can cause loss of life and property due to its geomorphological conditions. Highways, railways and settlement areas are in danger of rockfall and landslide. Mountain hazards such as rockfalls are generally seen in winter due to excessive rain and snow. Rockfall, which is a gravitational movement, occurs because of change in forces on rock masses. At last 50 years, 2956 rockfall events occurred in Turkey and 19422 people affected from rockfalls (Gökçe et al., 2008). Rockfalls that does not make significant damage usually unreported.

There are various reasons that can cause rockfalls. Earthquakes with high amplitude (Lunina et al., 2007), presence of joints (Simon et al., 2015), heavy rainfall (Wei et al., 2014), freeze-thaw cycle (Matsuoka and Sakai, 1999), undercutting of rocks by wind erosion (Admassu et al., 2012), weathering and tree root growth (Yılmaz et al., 2008) may cause rockfall.

Rockfall occurs at four different types, falling, bouncing, rolling or sliding depending on the geometric properties of rock blocks, slope angle and roughness with gravity effects. Potential energy is transformed to kinetic energy during rockfall event. Potential energy of a rock is higher when the slope height, which is defined as the vertical height, is higher.

The most commonly proposed solution is to design a barrier. In order to properly design a barrier, a digital elevation map (DEM) is needed. Unmanned aerial vehicle with GNSS can be used to create actual DEM of the study area.

2. STUDY AREA

Taurus Mountains, which are a part of Alp-Himalaya orogenic belt, are extending in an east-west direction along southern boundary of Turkey. Karahıdırlı village, which is located in central segment of Taurus Mountains, is exposed to rockfall event. Karahıdırlı village is located in Erdemli district, Mersin (Fig.1). This region has been suffering from rockfall threat and this is a concern on public safety. Upper Creteceous ophiolitic rocks have been dropping due to excessive rains.

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Figure 1. Location map of the study area

3. MATERIAL AND METHODS

Detailed evaluation of rockfall is required to select the best protection way. RocFall (Choi et al., 2009), Stone (Agliardi and Crosta, 2003), Rotomap (Papini et al., 2005), Rockyfor 3D (Corona et al., 2017), Colorado Rockfall Simulation Program (CRSP) (Moon et al., 2014), CONEFALL (Jaboyedoff and Labiouse, 2011) and Rockfall Analyst (RA) (Lan et al., 2007) are some of the software that model the rockfall trajectory.

RocFall uses a DEM, slope roughness, static friction angle and coefficient of restitution to determine velocity and bounce height at any points and run-out distance of rock blocks (Choi et al., 2009). Stone, which is a 3D GIS-based software, uses a digital terrain model, normal and tangential restitution coefficients and dynamic friction coefficient to determine the velocity, bounce height and runout distance of rock blocks (Guzzetti et al., 2002 and Agliardi and Crosta, 2003). Rotomap, which is a 3D model, uses normal and tangential coefficient of restitution, friction coefficient of rocks and limit angle to determine the run-out zone (Papini, 2005). Rockyfor 3D, uses a DEM, density, shape and dimensions of rock, mechanical properties of surface, normal and tangential coefficient of restitution and roughness of slope surface to model the rockfall trajectory (Corona et al., 2017). CRSP uses coefficient of restitution, surface roughness and slope geometries to determine impact energy, bounce height and run-out distance of falling rocks (Moon et al., 2014). CONEFALL, which uses DEM and coefficient of restitution can determine the maximum run-out distance and the velocity of rock blocks (Jaboyedoff and Labiouse, 2011). Rockfall Analyst, which is an extension of ArcGIS, uses a DEM, friction angle and coefficient of restitution to determine the velocity and run-out distance of rock blocks (Lan et al., 2007).

Detailed geological investigations; such as, types of faults, joints, rocks, rain intensity, weather conditions, weathering susceptibility and erosion potential of the region should be known to determine the possible areas that rockfall event may occur. DEM with high resolution at those areas with the help of unmanned aerial vehicle (UAV) will be created. By using a DEM, the velocity, bounce height, run-out distance and trajectory of rock blocks may be determined by using a computer software. That information will be used in rockfall barrier design.

The classical method in rockfall studies is to model the area in 3D to decide the rockfall trajectory. Runout distance, travel path, kinetic energy and bounce height of rocks will be determined by using DEM, mass of the rocks, coefficient of restitution (COR), static friction angle and surface roughness parameters.

To measure velocity rocks were rolled. Schweigl et al. 2003 used 2D simulation to suggest rockfall barrier design. Ansari et al 2018 have used 2D and 3D models to suggest rockfall barrier design. Fanos and Pradhan 2019 have used terrestrial laser scanner to obtain 3D point clouds of the area affected from rockfall.

Coefficient of restitution (COR), which is defined as the rate of velocity after collision and before collision, is the most important parameter to estimate rockfall hazard as all the computer software use that parameter. The equation of COR is given at Eq. (1).

$$COR=\frac{V_{after}}{V_{before}} \quad (1)$$

There are two components of COR, which are coefficient of normal (COR_N) and tangential (COR_T) restitutions and their equations are given in Eq. (2) and Eq. (3) respectively.

$$COR_N=\frac{V_{after\ N}}{V_{before\ N}} \quad (2)$$

$$COR_T=\frac{V_{after\ T}}{V_{before\ T}} \quad (3)$$

UAV has been used in engineering projects since last decade. Ulvi and Toprak (2016) and Şasi and Yakar (2018) have used UAV to model an archeological site. Saroglou et al (2018) have used a UAV to map the rockfall site area. UAV is a valuable tool to get information at the places where we cannot reach. Land surveying is time consuming and dangerous. Satellite images are not high resolution. Therefore, we need to use UAV to get actual information from the study area. UAV related research has been increasing over the last decade.

In this study, we used eBee-Plus integrated with real time kinematics global navigation satellite system (RTK/GNSS). GNSS device was set up in a fixed position to get high accuracy position data. The coordinates of the GNSS device was obtained by connecting the TUSAGA Active CORS network. GNSS device and UAV system were integrated to get the coordinates of the photos with high accuracy and precision. 162 photos were taken from the study area and imported into Agisoft Metashape Professional software to get Digital Surface Model (DSM) (Fig.2) and orthophoto (Fig.3) of the study area. Results are shown in table 1. Akar (2017) has stated that kriging method is the best interpolation technique in generating DEM.

Table 1. Analysis report

Item	Value
Number of images	162
Flying Altitute	373 m
Ground resolution	8.27 cm/pix
Camera location error	1.96734 cm
DSM resolution	33.1 cm/pix
DSM point density	9.15 points/m^2

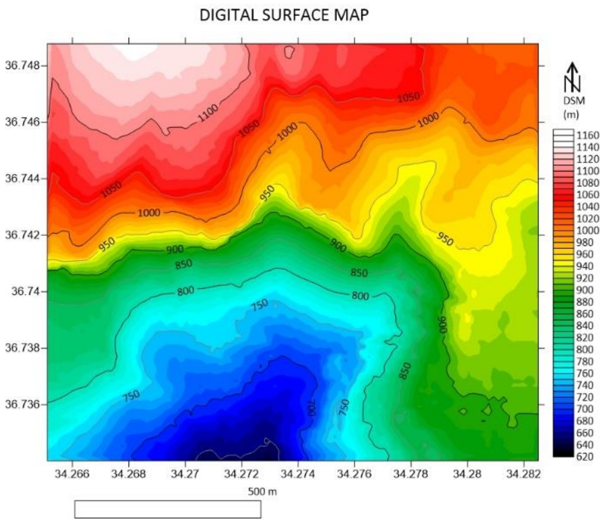

Figure 2. Digital surface map

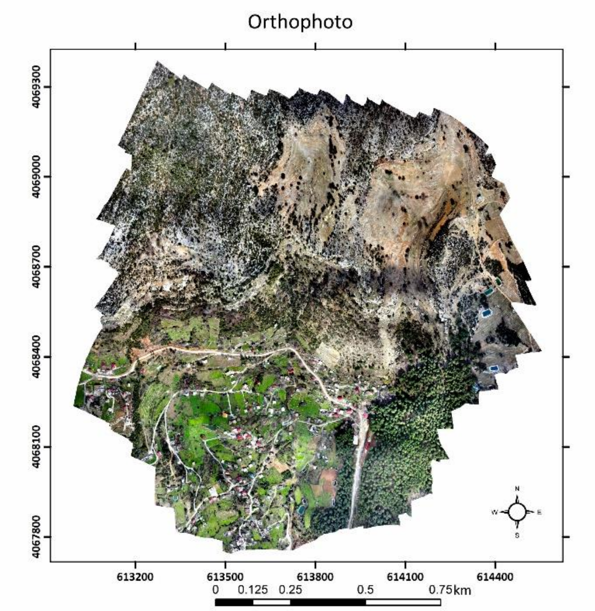

Figure 3. Orthophoto

4. ROCKFALL PROTECTION SYSTEMS

Rockfall barriers are important to protect people and buildings. They need to strong enough to stop the motion of large rock blocks, which have huge kinetic energy. Ditches, rock fences, barriers, wire-nets and ring nets with cables (Chau et al., 2002, Sasiharan et al., 2006 and Escallon et al., 2015) may be used to be protected from the harmful effects of rockfall. Geometrical arrangements of wires need to satisfy engineering standards. At historical places, they need to be constructed without disturbing the natural beauty.

5. DISCUSSION

Slope angle and the geometric properties of rock are the most important parameters at calculating the run-out distance of a rock. Predicting the volume of a rock that will fall and determining the coefficient of restitution of a rock are very challenging. When a rock hits a soft surface, it will bounce less; however, when a rock hits a hard surface, it will bounce much. Therefore, correctly modelling the rockfall trajectory is very difficult.

The knowledge of which joint and rock type may have tendency to make the rock fall more than others needs to be investigated. A database about rockfall activity including the coordinates and type of motion and cause of rockfall event should be constructed to help the researchers about understanding the rockfall phenomenon. By creating a rockfall distribution map, the danger zone will be identified. At each region, the dominant reason of rockfall event will be determined.

6. CONCLUSION

Karahıdırlı village is in danger of rockfall. Geologic properties of the rocks in the study area need to be investigated, in order to prevent from negative effects of rockfall. After modelling the study area, protection systems need to be constructed.

Topographical, geological and climatic factors play important role in rockfall event and it generally occurs due to combinations of those factors. While planning the transportation route and settlement closer to rocky slopes, rockfall hazard should be taken into account as it is an inevitable event. Rockfall protection systems should be implemented in order to prevent from death, injury and financial loss.

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