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ROCKFALL SUSCEPTIBILITY ZONING AND EVALUATION OF ROCKFALL HAZARD AT THE FOOT HILL OF MOUNTAIN ORLIAGAS, GREECE

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Abstract: Rockfalls are frequently generated in mountainous areas and threatened manmade environment. Therefore, the detachment of large size boulders and their fall track are issues that should be evaluated for urban planning and the construction of lifelines and road networks. In order to achieve this, several methodologies had been proposed and applied, regarding the evaluation of the landslide hazard. The most known methods concern the application of GIS software for the evaluation of the run-out distances of boulders and the simulation of the fall tracks. In this article, a delineation of areas susceptible to rockfalling at the foothills of mountain Orliagas, Greece is provided using the minimum shadow angle method and, in addition selected case studies of rockfalls were studied. These cases were simulated and analyzed using the Rocfall software while the employed parameters were tested and calibrated using silent witnesses. The outcome provided by this study, is that the simulated fall track and the rockfall run-out distance were in agreement with the spatial distribution of the reported boulders while the total kinetic energy and the bounce height during the fall track have been evaluated, thus can be used for the construction of remedial measures. In addition, as it is shown in the resulting by this study maps, the area between the villages of Ziakas and Spileo can be separated into two zones, A and B, regarding the landslide hazard for the road network, which is evaluated as low and very high, respectively.

Keywords: Rockfall, simulation, susceptibility, hazard, Orliagas, Greece

1. Introduction

A rock fall is a fragment of rock detached by sliding, toppling or falling that falls along a vertical or sub-vertical cliff, proceeds down slope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes (Varnes, 1978). Very occasionally, rockfall initiates catastrophic debris streams, which are even more dangerous (Hsu, 1975). Distinct evidences of rockfall are talus slope deposits at the foot of steep cliff faces, but rockfall also occurs on slopes covered with vegetation where evidence is less distinct (Dorren, 2003). Rockfalls range from small cobles to large boulders hundreds of cubic meters in size and travel at speeds ranging from few to tens of meters per second (Guzzetti et al., 2002). Minor rockfalls affect most of the rock slopes, whereas large size ones such as cliff falls and rock avalanches, affect only great rock slopes with geological conditions favourable to instability (Rouiller et al., 1998).

The detachment of rock from bedrock slope is triggered by several factors such as weathering, earthquake and human activities while the fall of a rock is determined by factors like the slope morphology and the direct surrounding of the potential falling rock (Dorren, 2003). The generation of rockfall is a rapid phenomenon and represents a continuous hazard in mountain areas worldwide. There are numerous examples of infrastructure destroyed or people killed by rockfall. To protect endangered residential areas and infrastructure, it is necessary to assess the risk posed by rockfall (Dorren, 2003).

The basic aim of this study is the evaluation of rockfall hazard at the foot hill of mountain Orliagas, Greece using simplified procedures regarding the assessment of the run-out distance of rockfalls and the simulation of their fall tracks. In particular, the procedures that were followed for the delineation of susceptible to rockfall-induced damages zones were based on the minimum shadow angle method and for the estimation of the values of kinetic energy and the bounce height of the boulders fall were resulted from the application of the Rocfall software.

2. Geology of the area

In this study, the rockfall hazard at the foot hill of mountain Orliagas, Greece was examined. The study area is located at the Northern Greece, close to the city of Grevena. The lithology of the area is mainly characterized by limestones and flysch as it is shown on the geological map (Fig.1) that was compiled using the surficial geological map of 1:50.000 scale provided by IGME and data collected from field surveys. Furthermore, the distribution of topographic slope was compiled using topographical data that were used as an input at the ArcInfo Software for the development of a DEM (Digital Elevation Model). In particular, the height of the slope is up to 1350 meter and the slope gradient varies between 25^o and 75^o (Fig. 2).

In addition, in figure 2 is shown the distribution of rockfalls, reported during our field survey and the profiles that were used for the simulation and the reconstruction of the rockfall event.

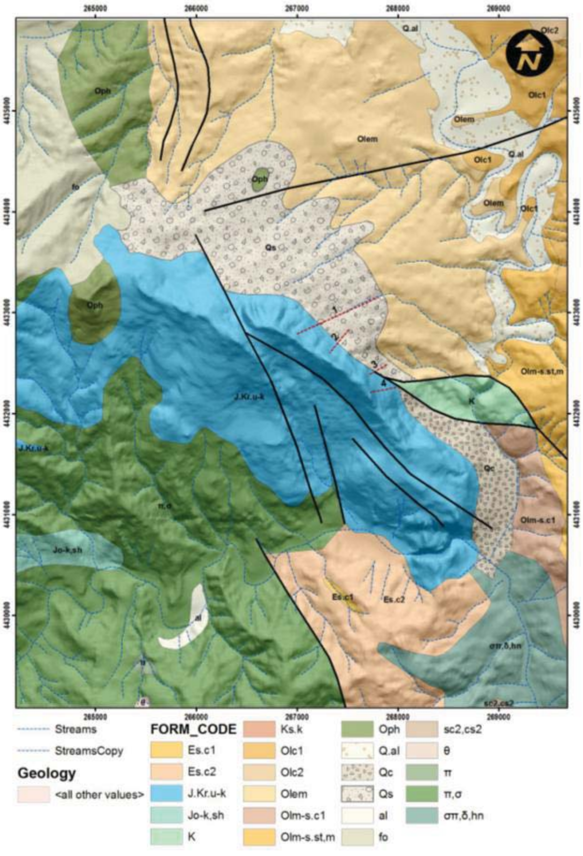

Fig. 1. Geological map of the study area (modified by the map of IGME)

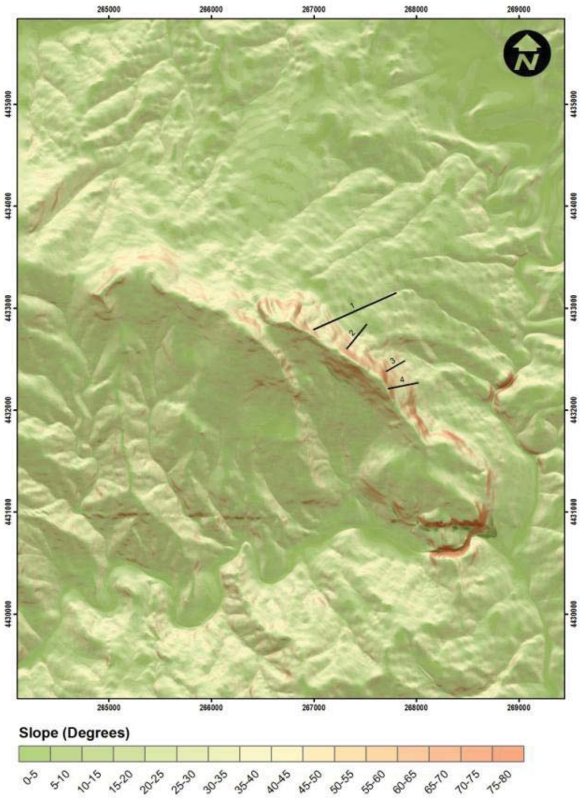

Fig. 2. Topographic map of the mountain Orliagas showing the slope degrees and the selected longitudinal profiles.

3. Evaluating the rockfall hazard

The goal of our study was twofold; the evaluation of the rockfall hazard in the study area and the estimation of the run-out distances of rockfall events. These goals were achieved by applying empirical methods and computer-based models concerning the landslide hazard mapping in regional scale and using software in order to simulate the fall of a boulder down a slope and to define the falltracks.

At the foot hill of mountain Orliagas, several boulders were reported and mapped using GPS instruments during a 3-days field survey. The spatial distribution of the boulders is influenced by the morphology and the slope characteristics and can be separated in 4 main zones (Fig.3). Based on these concentrations, four longitudinal profiles have been created in order to evaluate the rockfall hazard and the values of the basic parameters of the falls. Examples of boulders are shown in figure 4, while the most characteristic large scale rock to can be seen in figure. Moreover, several silent witnesses like broken trees were identified and used for the simulation of the downslope movement of the boulders. Furthermore, a simplified procedure for the estimation of the run-out distance of a rockfall was initially applied within this particular area in order to evaluate the rockfall susceptibility.

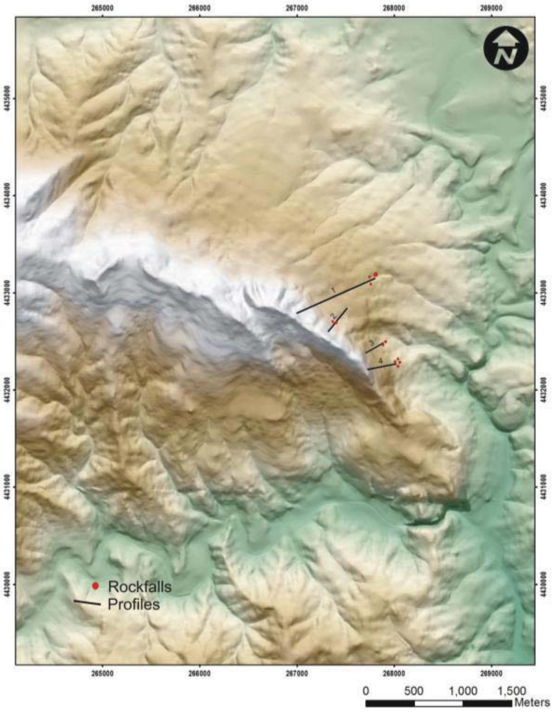

Fig. 3. Map showing the location of boulders and the four selected longitudinal profiles

4. Estimating the run-out distance

Empirical rockfall models are generally based on relationships between topographical factors and the length of the run-out zone (Dorren, 2003). Usually, the parameters to describe the rockfall runout zones can be the angle or the horizontal distance (Petje et al. 2005). In general, two methods are mainly applied for the estimation of the maximum distance that a boulder can reach (Fig. 5). The first model, Fahrboschung angle, was suggested by Heim (1932) and predicts the run out zone using the angle that is defined by the horizontal plane and the line form the top of a rockfall source scar to the stopping point for any given rockfall. The second method is the model known as minimum shadow angle proposed by Evans and Hungr (1993) which were based on Lied (1977). According to them, the area beyond the base of a talus slope that is reached by large size boulders is termed the rockfall shadow and the equivalent shadow angle is defined as the angle between the outer margin of the shadow and the apex of talus scope. The distal part of the shadow often contains only very few boulders, which are sparsely distributed on the surface (Evans and Hungr, 1993). Evans and Hungr (1993), having investigated 16 talus slopes in British Columbia, suggested that a minimum shadow angle of 27.5° is adequate for a preliminary estimation of a rockfall runout distance while Dorren (2003) having compared the outcomes of several studies, concluded that the angle lies between 22° and 30°.

Fig. 4. Old evident boulder.

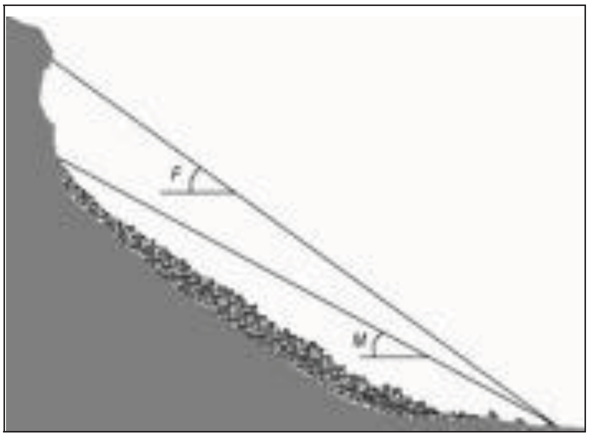

Fig. 5. Sketch showing the evaluation of Fahrboschung angle (f) and the minimum shadow angle (m)

In our study, the shadow angle method was taken into account because shows acceptable reliability at a large scale (Meibl, 2001; Copons and Vilaplana, 2008) and due to the fact that is more suitable comparing to Fahrboschung angle model which predicts an excessively long travel distance (Evans and Hungr, 1993; Wieczorek et al., 1999). Taking into consideration the proposed values of shadow angle, 22°, 27,5° and 30°, relevant zones of run-out distances were compiled (Fig. 6).

As it is shown in figure 7, the area between villages of Ziakas and Spileo can be separated into two zones regarding the evaluation of the longest site that a boulder can reach. In particular, at zone A, the manmade environment and the road network was constructed outside the delineated zones. Thus, the landslide hazard regarding the road network can be characterized as very low. On the contrary, at zone B, the run-out distances of the boulders are within the areas delineated by the shadow angles of 30^o, 27.5^o and 22^o and the manmade environment such as the road network, was constructed within these zones, thus is under high level hazard and protection measures should be constructed in order to avoid rockfall-induced damages.

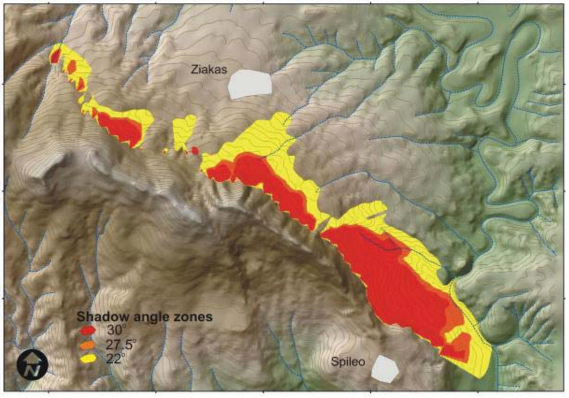

Fig. 6. Rockfall susceptibility map at the foot hill of mountain Orliagas that was compiled using the minimum shadow angle method.

5. Simulating the rockfall trajectories

In addition, in our study the fall track of particular boulders was examined based on four longitudinal profiles (Fig. 8). The selected slope profiles were validated using the marks of the boulders on the area and the Flow direction function of the ArcInfo software. Moreover, silent witnesses such as broken trees and old evident rockfalls were recorded using GPS instruments and were also used for the development of these profiles.

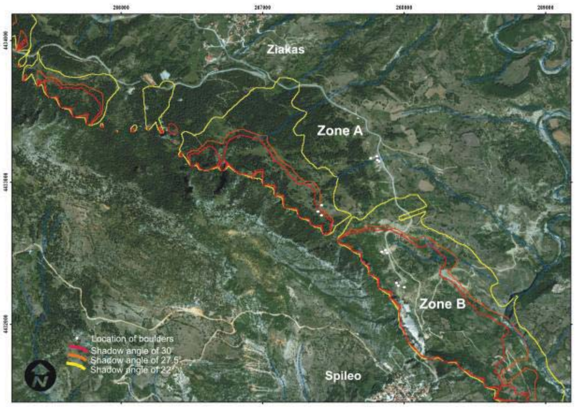

Fig. 7. Delineation of zones A and B.

The fall tracks of the rockfalls were simulated using the Rocfall software, which is a robust, easy to use computer program that is available from Rocscience and performs a probabilistic simulation of rockfalls and can be used to design remedial measures and test their effectiveness (Stevens, 1998).

As it was shown in several applications of this methodology, the runout of a rockfall is influenced by the geological characteristics of the slope materials and the roughness of slope. The former influence the loss of energy during impacts and the latter the type of rockfalling. Although the fact that in our study we simulate the falltrack of a large size boulder, we took into consideration the slope roughness by employing a value of 5 in the relative field of Rocfall software.

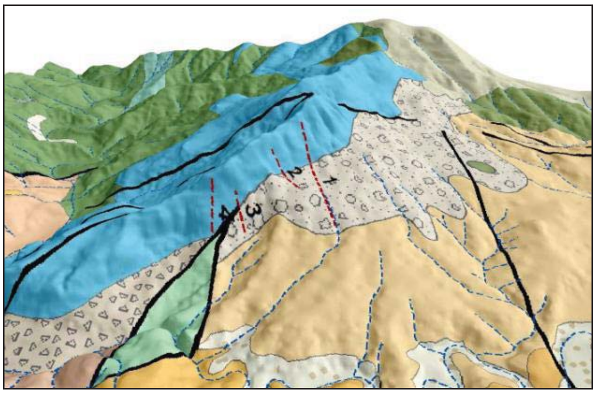

Fig. 8. 3D projection of mountain Orliagas showing the selected longitudinal profiles.

Moreover, one of the most important and difficult issues for the simulation of a falltrack is the reliability of the employed material properties. Typical values for the coefficient of normal (Rn) and targential (Rt) restitution used in rockfall analyses range from 0.3 to 0.5 and from 0.8 to 0.95, respectively (Stevens, 1998). In this study, the proposed by Rocfall software values of Rn and Rt for the formation of talus cone with vegetation were used while the relative employed parameters for the limestone were based on the suggestions of Robotham et al (1995). The initial points in the models have been defined during the field survey thus, defined as a single point in Rocfall software.

The validation of the employed parameters was accomplished using the profile_2. In particular, both the starting point and the run-out distance of the boulders were mapped during our field survey and recorded using GPS instruments. In order to simulate the fall track, we used the parameters proposed by Stevens (1998) and by Rocfall software. The output of the simulation, regarding the horizontal location of the boulders (Fig. 9), is in agreement with the observed fall track, validating our scenario.

Having validated the basic parameters of the geological units for the simulation of the fall track, we proceeded to the development of scenarios regarding the other three profiles. The aim of the simulation was the evaluation of the run-out distances at the selected sites and the estimation of the kinetic energy and the bounce height of the boulders with-

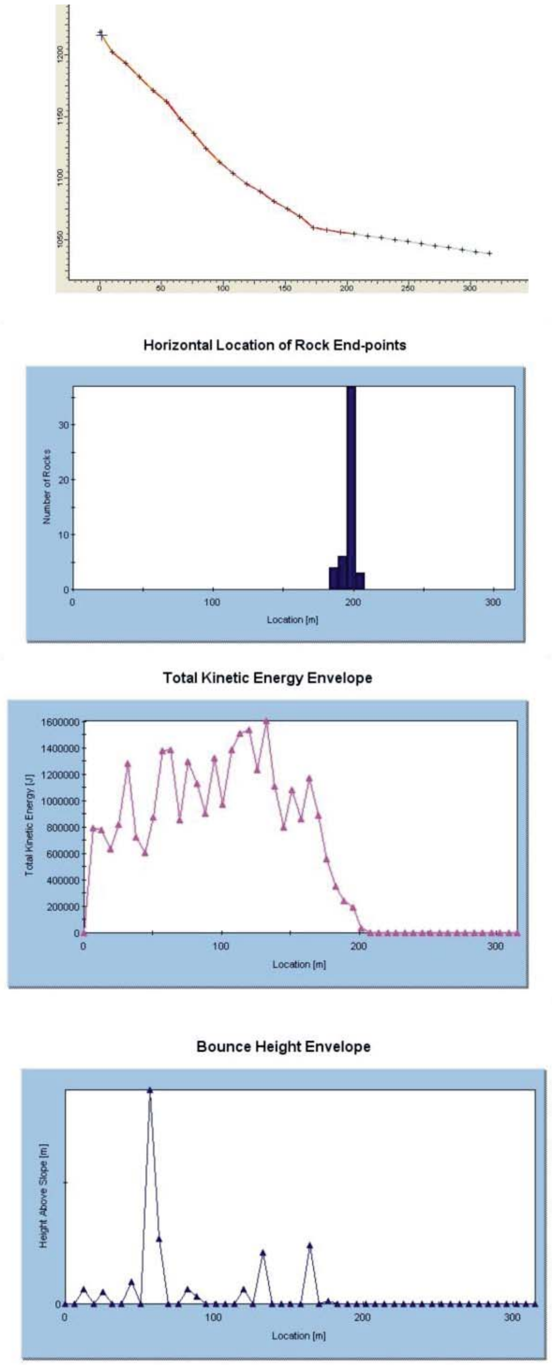

Fig. 9. Basic parameters of profile_2: longitudinal profile, run-out distance, total kinetic energy and bounce height of the boulders

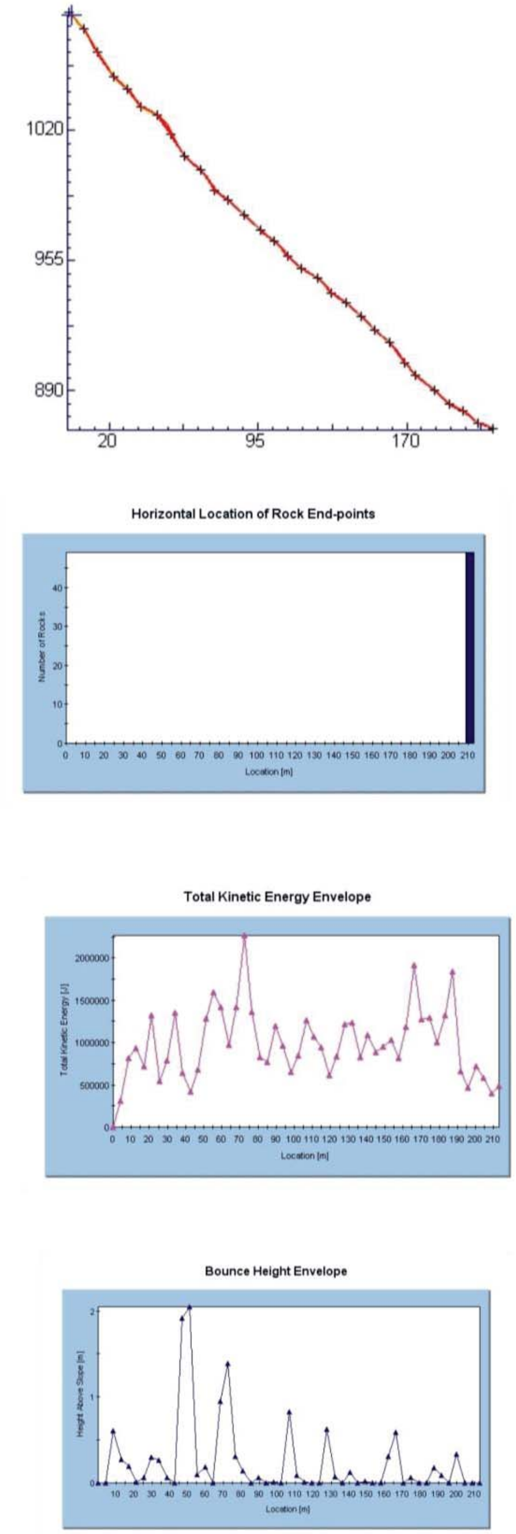

Fig. 10. Basic parameters of profile_3: longitudinal profile, run-out distance, total kinetic energy and bounce height of the boulders.

in their fall track. The estimated values could be used for the design and construction of remedial measures in order to avoid possible damages to the road network triggered by rockfalls.

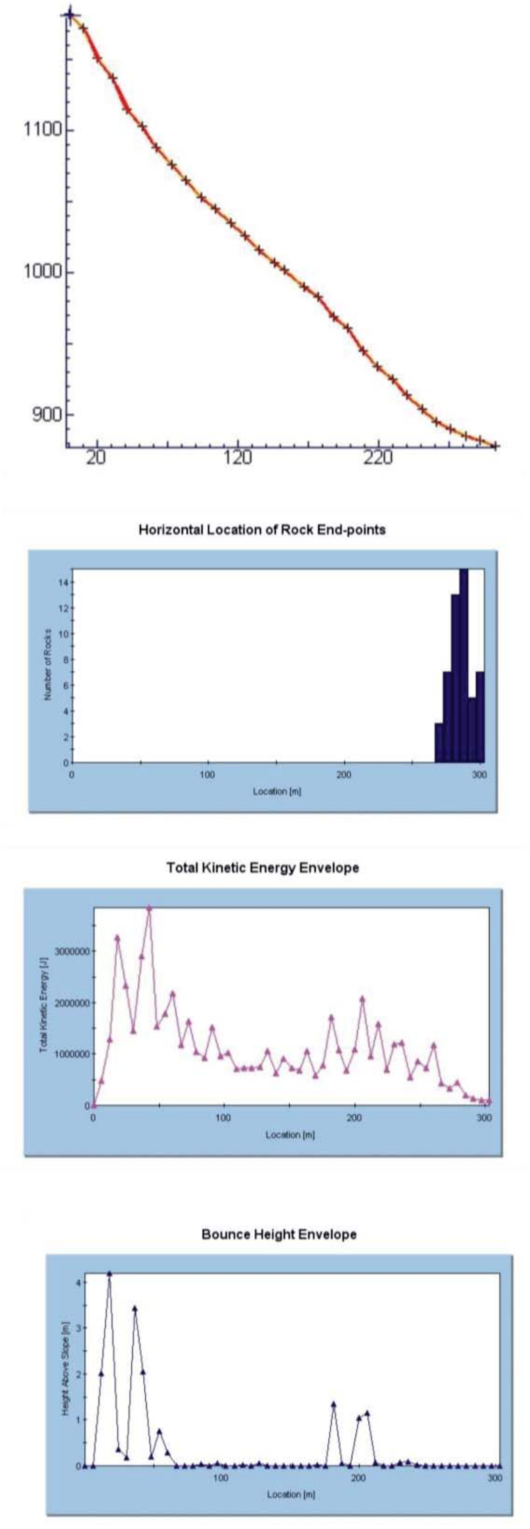

Fig. 11. Basic parameters of profile_4: longitudinal profile, run-out distance, total kinetic energy and bounce height of the boulders.

In particular, profile_3 concerns the fall track of boulders that are located within zone B, as it shown in figure 10. The result of this simulation indicates that a boulder can travel at a distance farthest than the road network and thus, causing damages to it. The same conclusion was more or less arisen from the longitudinal profile_4. This fall track is close to the area where rock avalanches are mapped and shows that the run-out distance of the boulders reaches the road. Therefore, in both cases and in order to prevent rockfall-induced structural damages, remedial measured should be developed using the values of kinetic energy and the bounce height of the rockfalls that were estimated in this study and provided in figure.

Finally, the case study of profile_1 is more complicated than the previous ones. At the end of the profile, a large size boulder and smaller ones are located and used as silent witnesses. However, as it is shown in this study by the developed simulation (Fig. 12), the run-out distance cannot reach this area. Although the fact that we developed several scenarios using different volume of rockfalls, none could even get closed to the end of the fall track. Thus, we concluded that the position of this large-scale block at this huge runout distance should be resulted not only by one single event of rockfall but must be either the cumulative result of more than one event or the outcome of a landlslide that moved this block downward.

As an outcome of the simulation of three different fall tracks within the two zones, we concluded that boulders detached from the mountain Orliagas couldn’t reach the manmade environment at the first one. However, regarding the zone B, this study concluded that in two cases (profiles 1 and 2), rockfalls could reach the road network, thus triggering damages on it.

6. Conclusions

The aim of this paper was twofold: evaluation of rockfalls hazard on regional scale at the foot hill of mountain Orliagas, in the area of village Ziakas and simulation of the fall tracks of boulders at selected profiles in order to examine the rockfall-induced damages to manmade environment. The former was evaluated using GIS-based methods proposed by geologists and geomorphologists and applied in several countries. In particular, the run-out distance of a boulder is estimated using the shadow angle method and areas based on the run-out distance of a future rockfall event were deli-

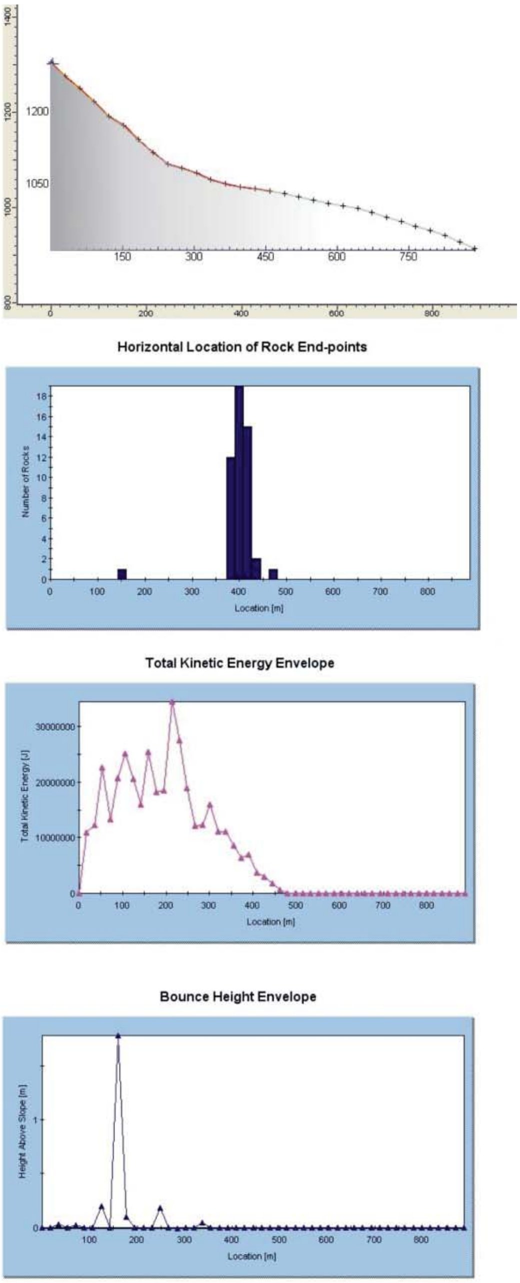

Fig. 12. Basic parameters of profile_1: longitudinal profile, run-out distance, total kinetic energy and bounce height of the boulders.

neated. In addition, longitudinal profiles were developed based on observations during a filed survey and silent witnesses regarding the track of old evident rockfalls. These profiles have been incorporated into the Rocfall software and simulation of the downslope movement of large scale rocks was developed. The outcome provided by this simulation indicates that the road network linking the villages of Ziakas and Spileo could be separated into two zones. The hazard in the first one is very low while the possibility of rockfall-induced damages to the second zone is high. Moreover, basic parameters of the fall tracks of the boulders, such as the kinetic energy and the bounce height, were estimated and could be used in the design of remedial measures.

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