Analysis and evaluation of rockfall hazard around Afyon Castle, Turkey

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Abstract: The Afyon Castle is a tourist destination and a historical site in the City of Afyon in Turkey. The castle is located on a steep hill, with a height of 226 m. In close proximity to the castle there are settlements. The hill consists of volcanic trachitic andesite. The rock contains columnar joints and flow layering. Due to these discontinuities, blocks with varying sizes have fallen down in the past. The settlement areas near the castle are now under threatened because of the rockfall risk. In this study, rockfall analysis was carried out along two sections of the hill. Fall-out distance, bounce height, kinetic energy and velocity of the rocks along each section were investigated. The results of the analyses were evaluated to the areas delineated as susceptible to rockfall risk highlighted. Possible remedial measures were suggested on the basis of the field observations and the rockfall risk evaluation.

Résumé: Le Château d'Afyon est une destination de touriste et un site historique dans la Ville d'Afyon en Turquie. Le château est localisé sur une colline escarpée, avec une hauteur de 226 m. Tout près du château il y a des règlements. La colline consiste en volcaniques trachitic andesite. La roche contient des joints colomnaires et épaisseur écoulment. En raison de ces discontinuités, dans le passé, les blocs avec les tailles variables sont tombé. Les secteurs de règlement prés du château sont maintenant dessousmenacés à cause du risque d'éboulement rocheux. Dans cette étude, l'analyse d'éboulement rocheux a été exécuté le long de deux sections de la colline. La distance de retombées, la hauteur de bond, l'énergie cinétique et la vélocité des rochers le long de chaque section ont été examinées. Les résultats de l'analyse ont été évalué aux secteurs susceptibles au risque de éboulement rocheux. Les mesures réparatrices possibles ont été suggérées sur les base des observations de champ et l'évaluation de risqué d'éboulement rocheux.

Keywords: case studies, geological hazards, igneous rock, protection, slope stability

INTRODUCTION

Rockfall is a downslope movement of detached rocks in any size by travelling through the air. The rockfall causes loss of life and property because of its very rapid movement. It may be caused by jointing, weathering, freeze-thaw, water effect, earthquake, and tree roots (Chen, Chen, & Huang 1994; Wasowski and Gaudio 2000; Marzorati, Luzi, & Amicis 2002; Dorren 2003). Depending on the shape of the slope, rockfall may be in the form of free fall, bouncing, or rolling (Ritchie 1963). As the profile changes, two or more of the rockfall modes may also be observed. Additionally initial velocity, weight and shape of the blocks, and the properties of the slope forming material may control rockfall events (Giani 1992; Azzoni, Barbera, & Zaninetti 1995; Dorren, 2003). Empirical/experimental techniques or modelling can be used for the rockfall analysis (Giani 1992; Evans & Hungr 1993; Okura, Kitahara, Sammori, & Kawanami 2000). The rockfall analysis with 2D computer modelling can be used to predict the block trajectory, travel distance, velocity, bounce height and kinetic energy of the blocks (Schweigl, Ferretti & Nössing 2003). The coefficient of restitution is one of the most important and most difficult parameters to assess for the analysis. Many researchers have performed studies to determine the coefficient of restitution (Budetta & Santo 1994; Azzoni *et al*. 1995; Schweigl *et al.* 2003; Chau, Wong & Lee 1998**;** Chau, Wong & Wu 2002; Agliardi & Crosta 2003; Dorren, Maier, Putters & Seijmonsbergen 2004). However, these values may be significantly different depending on the conditions of each site. For this reason, the coefficient of restitution with normal and tangential components should be determined individually for each site. Field tests or back analysis of the fallen blocks may be used for obtaining these coefficients. Based on the analysis, remedial measures such as avoiding the site, cleaning of loose rock blocks, bolting, construction of retaining wall, installation of protective fence and ditch construction, should be taken into consideration to eliminate or mitigate the rockfall hazard (Spang & Rautenstrauch 1988; Paronuzzi 1989; Chen *et al.* 1994; Peila, Pelizza & Sasudelli 1998; Nicot, Cambou, & Mazzoleni 2001; Chau, Wong, Liu & Lee. 2003**;** Schweigl *et al.* 2003)

The Afyon Castle is a tourist destination and a historical site in the City of Afyon in Turkey (Figure 1) where the continental climate is dominant. The summers are hot and dry; the winters are cold with rain and snow. The castle is located on a steep hill, with a height of 226 m (Figure 2). In close proximity to the castle there are settlements and historical buildings. Falling blocks with varying sizes have occurred and the settlement areas around the castle have been historically and are currently in danger of rockfalls. In this study, the rockfall hazard of the southern part of the castle area was investigated because urgent planning control is required in this zone. Two dimensional rockfall analyses were carried out along two profiles. Various rockfall related parameters such as fall-out distance, bounce

height, kinetic energy and velocity of the rocks along each section were simulated by using RocFall 4.0 software (Rocscience 2002). The results obtained from the analyses were used to delineate areas at risk from rockfall. Possible remedial measures for the investigated area were also suggested.

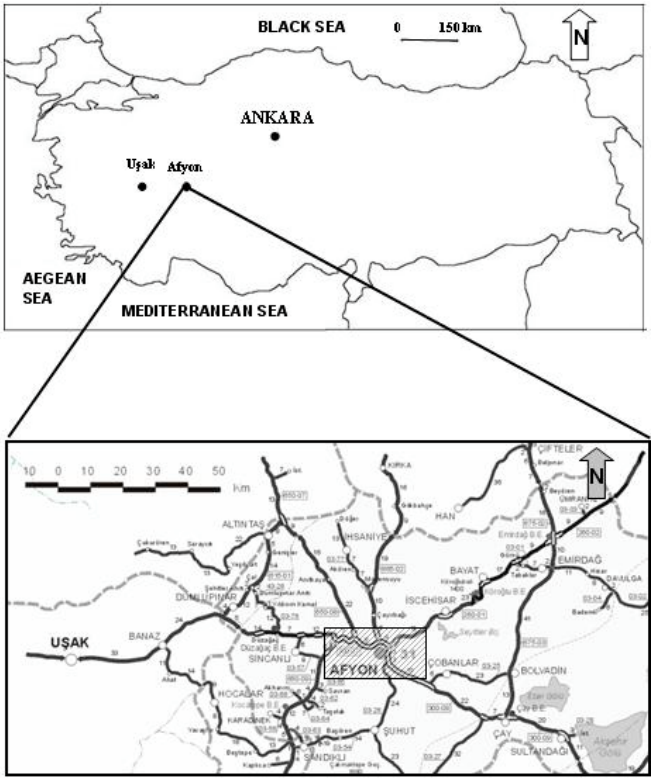


Figure 1. Location map of the study area

(a) (b)

Figure 2. General view of the Afyon Castle and settlement area: (a) northeastern and (b) southern part of the hill

GEOLOGICAL SETTING

Various geological units are exposed in the close vicinity of the Afyon Castle. However, the Castle is located in volcanic rocks of Miocene Age (Figure 3). Based on the petrographical and geochemical studies performed by Basarır & Kun (1982), the rock type is trachitic andesite. Macroscopically, the trachitic andesite is grey, slightly weathered, and strong. Although it has a massive appearance, it includes both flow layering and cooling joints (Figure 4), which cause some blocks to detach. Microscopically, it has porphyritic texture and mainly contains sanidine, biotite, plagioclase, hornblende and augite. The size of the sanidine is as large as 25 mm (Figure 5) and it forms about 15% of the whole rock. The rock locally contains xenoliths. Existing active faults in the close vicinity of the study area may cause vibration of the ground, and thus giving rise to rockfalls around the castle and the settlement.

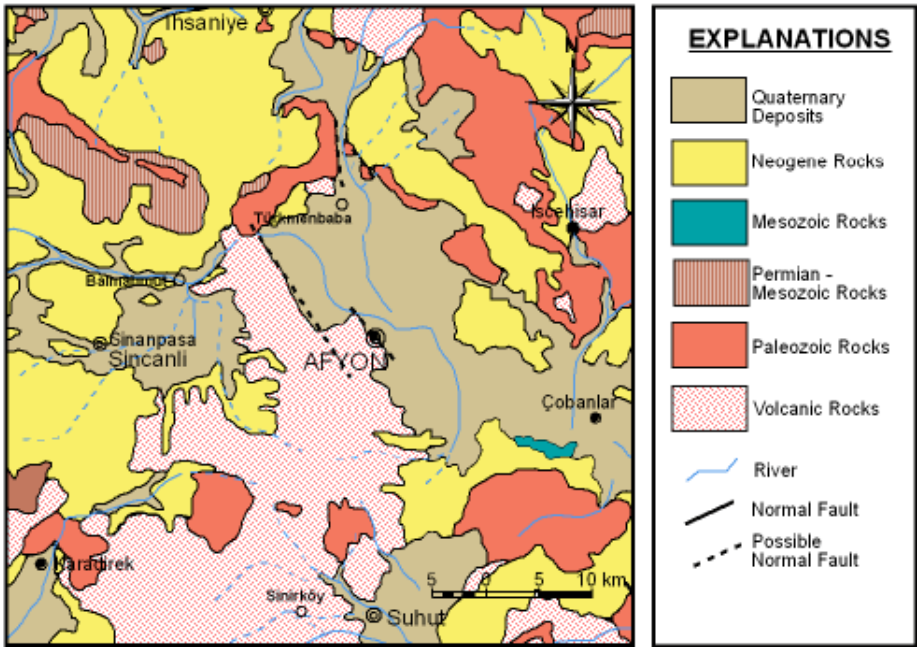


Figure 3. Geological map of the study area (modified from MTA 1/500 000 scaled geological map)

(a) (b)

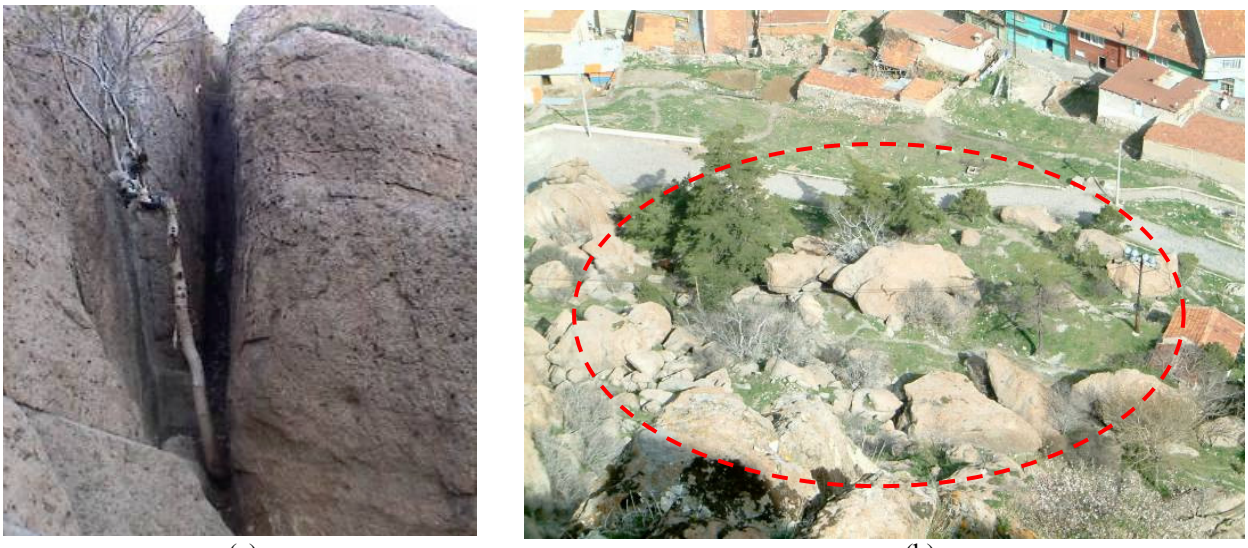
Figure 4. Photograph of (a) the cooling joints and (b) flow layering in the trachitic andesite

Figure 5. Sanidine phenocrystals in the trachitic andesite

ANALYSIS OF ROCKFALL

Field studies performed around the Afyon Castle revealed that there was evidence of various historical rockfalls. The spacing of the flow layering and cooling joints may range from a few tens of centimetres to a few metres. As a result, both small and large blocks are formed. Jointing, freeze-thaw, water effects, earthquake, and tree roots (see Figure 6a) are the main causes of rockfalls. The largest fallen block observed is nearly 8 tons (Figure 6b). RocFall 4.0 software of Rocscience (2002) was used for the rockfall analysis.

For the assessment of the coefficient of restitution of the trachitic andesite, the positions of the fallen blocks were placed on the available topographic map at a scale of 1:1000. The weight of each block was estimated using the volume and the unit weight of the block. Back analysis was then performed to assess the coefficient of restitution for this site. Based on the analysis, the normal and tangential coefficients of restitution of the rocks were found as 0.46 and 0.71, respectively. These and other selected parameters (see Table 1) were used for the rockfall analysis to determine the fall-out distance, bounce height, kinetic energy and velocity of the rocks along two sections (profiles) (Figure 7) that were selected at the southern part of the Castle as suggested by the local authorities of Afyon municipality. Concerning the analysis, rocks of different weights representing the field conditions were used. The results of the analysis are summarized in Table 2.



(a) (b)

Figure 6. Photographs showing (a) the enlargement of the joint due to tree roots, (b) various sizes of blocks fallen down

Table 1. Parameters used in rockfall analysis

Parameters	Value
Coefficient of normal restitution	0.46 ± 0.04
Coefficient of tangential restitution	0.71 ± 0.08
Friction angle (degrees)	40
Slope roughness	2
Initial velocity (m/sec)	1 ± 0.5
Number of throw	1000 rocks
Minimum velocity cut-off (m/sec)	0.1
Sampling interval	50

Table 2. Results of rockfall analyses for the profiles 1 and 2

Profile #	Weight of the rockfall (kg)	Horizontal location of end-points (m)	Maximum bounce height (m)	Maximum total kinetic energy (J)	Maximum translational velocity (m/sec)
1	10	208	28	9458	38
	100	203	27	89850	38
	1000	208	27	897984	42
	10000	214	28	9012490	42
2	10	205	14	5281	31
	100	205	13	46923.2	30
	1000	205	14	462534	30
	10000	205	14	4783010	30

Based on the rockfall analyses, the fall-out distance ranged between 205m and 214m from the source area located just beneath the Castle wall. Bounce height reaches to a maximum value of 28m along the trajectory. Maximum kinetic energy is in the order of 9012 kJ. The blocks attain a velocity of 42 m/s along the trajectory. Although very high kinetic energies and velocities of the blocks are obtained, they decrease along the profile.

EVALUATION OF ROCKFALL HAZARD

The rockfall analyses performed for the southern part of the Afyon Castle reveal that there exists a rockfall danger zone. The extent of the zone is shown in Figure 7. This zone partly includes areas of settlement. The local municipality authorities indicate that there are also several historical buildings that must be protected in this zone. Total evacuation of the danger zone is not preferred by the authorities. Therefore, remedial measures against rockfall hazard are considered in this study. Retaining wall and wiremesh remedial measures are not preferred as they would adversely disturb the appearance of the historical Castle. Ditch construction is not effective for this site because of the high bounces of the blocks.

There are many loose blocks ready to fall down with little triggering effects. These should be totally cleaned before adopting a suitable remedial measure. Rock bolting may be applied especially to hold relatively large blocks near the lower levels of the Castle. However, many parts of the hill are difficult to access. Additionally, the existing joints beyond the rock bolts may become separated from the main rock body as time passes. For that reason, rock bolting may be considered in engineering practice, but it should be supported by another remedial measure. The installation of the protective fences may be considered for those blocks which may fall down.

The suggested locations of the protective fences are given in Figure 7. The locations are selected so that (a) the fences are between the Afyon Castle and the settlement area, (b) the fences are where minimum kinetic energy and bounce height are achieved, and (c) the existing pathway for tourists (thin red line within the danger zone in Figure 7) is protected.

This paper describes the outcomes of the rockfall hazard analysis for the southern part of an ongoing project which includes all around the Afyon Castle. Therefore, the remedial measures suggested in this paper may be considered to be preliminary at this stage. They will be re-evaluated and extended when the project is completed.

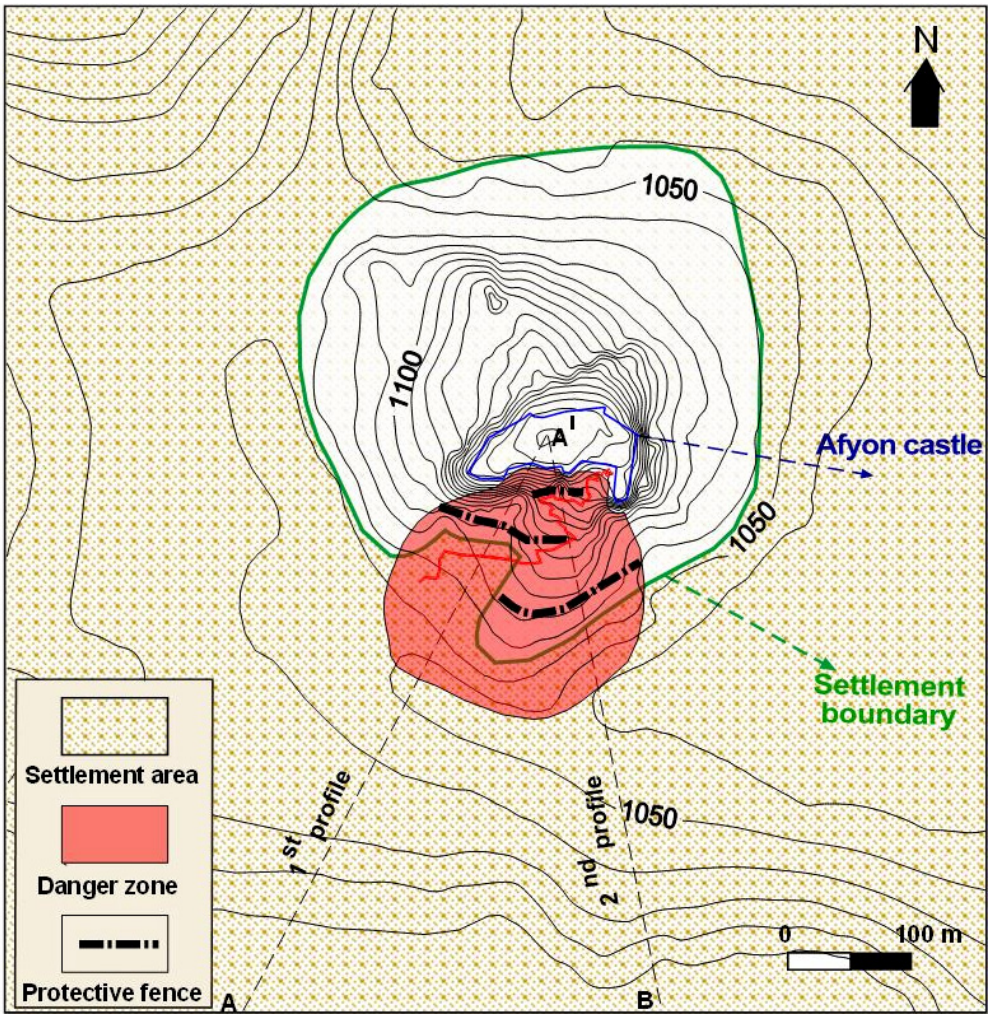


Figure 7. Map showing the extent of rockfall danger zone for the southern part of the Afyon Castle and the possible locations of the protective fence as remedial measures

CONCLUSIONS AND RECOMMENDATIONS

The Afyon Castle is a tourist destination and a historical site in the City of Afyon in Turkey is located on a steep hill, with a height of 226 m. There is a potential of rockfall danger for the areas around the Castle. In this study, the rockfall hazard of the southern part of the Castle area was investigated through two dimensional rockfall analyses. The analysis was carried out along two profiles. Rockfall related parameters such as fall-out distance, bounce height, kinetic energy and velocity of the rocks along the sections were assessed. Based on the rockfall analyses, a rockfall danger zone delineated. Cleaning of loose blocks, bolting where necessary and protective fences are all suggested for the southern part of Afyon Castle.

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