

Assessment of rockfall hazard around Afyon Castle, Turkey

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Received: 3 October 2006 / Accepted: 30 December 2006 / Published online: 24 January 2007
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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 trachitic andesite. The rock contains columnar joints and flow layering. Owing to these discontinuities, blocks of varying sizes had fallen down. The settlement areas near the Castle are now in danger because of the rockfall risk. In this study, rockfall analysis was carried out along nine profiles of the hill. Fall-out distance, bounce height, kinetic energy and velocity of the rocks along each profile were investigated. The results of the analyses were evaluated, and the areas delineated as susceptible to rockfall risk are highlighted. Remedial measures including rock bolts and protective fences were suggested on the basis of the field observations and the rockfall risk evaluation.

Keywords Afyon Castle · Andesite · Rockfall · Risk · Zonation map

Introduction

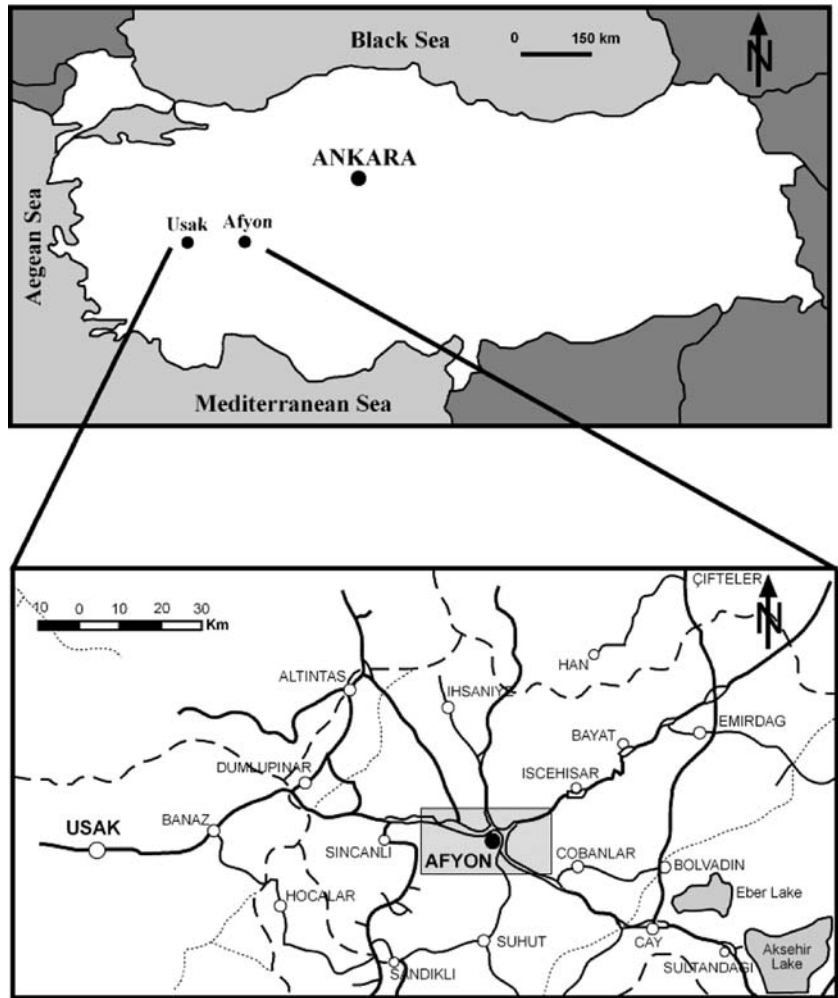
Rockfall is a downslope movement of detached rocks in any size by travelling through air. The rockfall may be formed due to jointing, weathering, freeze–thaw,

water effect, earthquake, and tree roots (Chen et al. 1994; Wasowski and Gaudio 2000; Marzorati et al. 2002; Dorren 2003). It causes loss of life and property because of its very rapid movement. The rockfall may be in the modes of free fall, bouncing or rolling depending on the shape of the slope (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 event (Giani 1992; Azzoni et al. 1995; Dorren 2003). Empirical/experimental techniques or modelling can be used for the rockfall analysis (Giani 1992; Evans and Hungr 1993; Okura et al. 2000). Two-dimensional computer modelling can be effectively used to predict the block trajectory, travel distance, velocity, bounce height and kinetic energy of the blocks (Schweigl et al. 2003). The coefficient of restitution is one of the most important and most difficult parameter to assess for the analysis. Many researchers have performed studies to determine the coefficient of restitution (Budetta and Santo 1994; Azzoni et al. 1995; Schweigl et al. 2003; Chau et al. 1998, 2002; Agliardi and Crosta 2003; Dorren et al. 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. On the basis of the analysis, rockfall hazard zoning may be done (Jaboyedoff et al. 2005) and remedial measures such as avoiding the site, cleaning of loose rock blocks, bolting, construction of retaining wall, installation of protective fence and ditch construction may be taken into consideration to

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Fig. 1 Location map of the study area



eliminate or mitigate the rockfall hazard (Spang and Rautenstrauch 1988; Paronuzzi 1989; Chen et al. 1994; Peila et al. 1998; Nicot et al. 2001; Chau et al. 2003; Schweigl et al. 2003).

The Afyon Castle is a tourist destination and a historical site in the City of Afyon in Turkey (Fig. 1) where the continental climate is dominant. The summers are hot and dry; the winters are cold with rain and

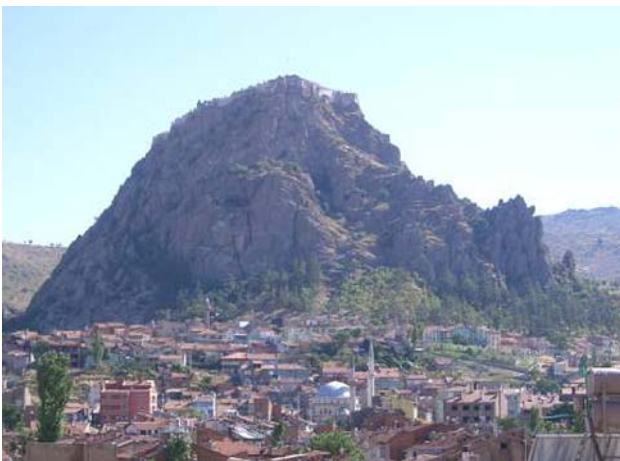


Fig. 2 General view of the Afyon Castle and settlement area

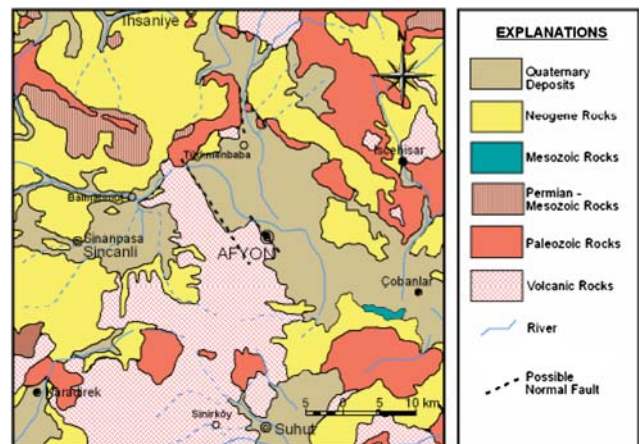


Fig. 3 Geological map of the study area (modified from MTA 1963)

Fig. 4 Photograph of **a** the cooling joints and **b** flow layering in the trachitic andesite

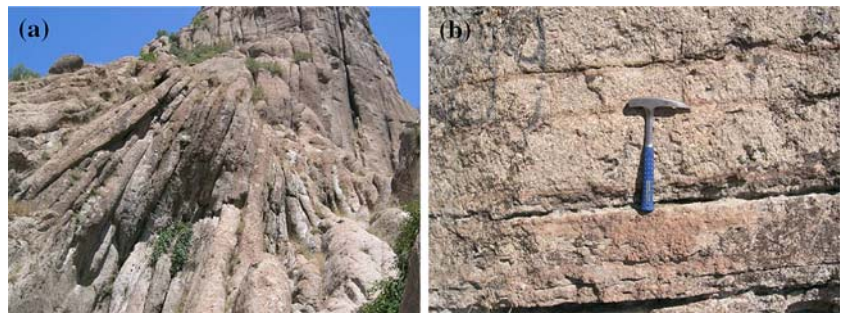


Fig. 5 Sanidine (S) phenocrystals in the trachitic andesite

snow. The Castle is located on a steep hill at a height of 226 m (Fig. 2). In close proximity to the Castle, there are settlements and historical buildings that should be protected. However, rock blocks of varying sizes had fallen down and the settlement areas around the Castle have been in danger of rockfall. In this study, the rockfall hazard around the Afyon Castle was investigated. Two-dimensional rockfall analyses were carried out along nine profiles. Various rockfall-related

parameters such as fall-out distance, bounce height, kinetic energy and velocity of the rocks along each profile were simulated by using RocFall 4.0 software (Rocscience 2002). The results obtained from the analyses were used to delineate the areas having rockfall risk. Possible remedial measures for the investigated area were also suggested.

Geological setting

Various geological units are exposed in the close vicinity of the Afyon Castle. However, the Castle is located on the volcanic rocks of Miocene age (Metin et al. 1987) (Fig. 3). On the basis of the petrographical and geochemical studies performed by Basarir and Kun (1982), the rock is trachitic andesite. Macroscopically, the trachitic andesite is grey and slightly weathered. Although it has a massive appearance, it includes both flow layering and cooling joints (Fig. 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 crystals may be as large as 25 mm (Fig. 5) and they form about 15% of the whole rock. The rock locally contains xenoliths. There are active faults in the

Table 1 Laboratory test results for the andesite

Properties	Standard used for testing	Number of tests	Mean ± SD
Effective porosity (%)	ISRM (1981)	10	8.19 ± 0.77
Dry unit weight (kN/m ³)	ISRM (1981)	10	24.02 ± 0.20
Saturated unit weight (kN/m ³)	ISRM (1981)	10	24.83 ± 0.27
Water absorption under atmospheric pressure—by weight (%)	TS 699 (1987)	10	2.40 ± 0.19
Water absorption under pressure—by weight (%)	ISRM (1981)	10	3.35 ± 0.35
Saturation coefficient	TS 699 (1987)	10	0.72 ± 0.02
Dry sonic velocity ^a (m/s)	ISRM (1981)	10	2721.75 ± 472.18
Saturated sonic velocity ^a (m/s)	ISRM (1981)	10	3146.00 ± 339.74
Dry uniaxial compressive strength (MPa)	ISRM (1981)	10	49.37 ± 2.61
Saturated uniaxial compressive strength (MPa)	ISRM (1981)	10	32.50 ± 2.06
Dry point load strength index, I _{s (50)} (MPa)	ISRM (1985)	10	3.71 ± 0.58
Saturated point load strength index, I _{s (50)} (MPa)	ISRM (1985)	10	2.06 ± 0.21

SD Standard deviation

^a Pundit-plus 54-kHz transducers are used

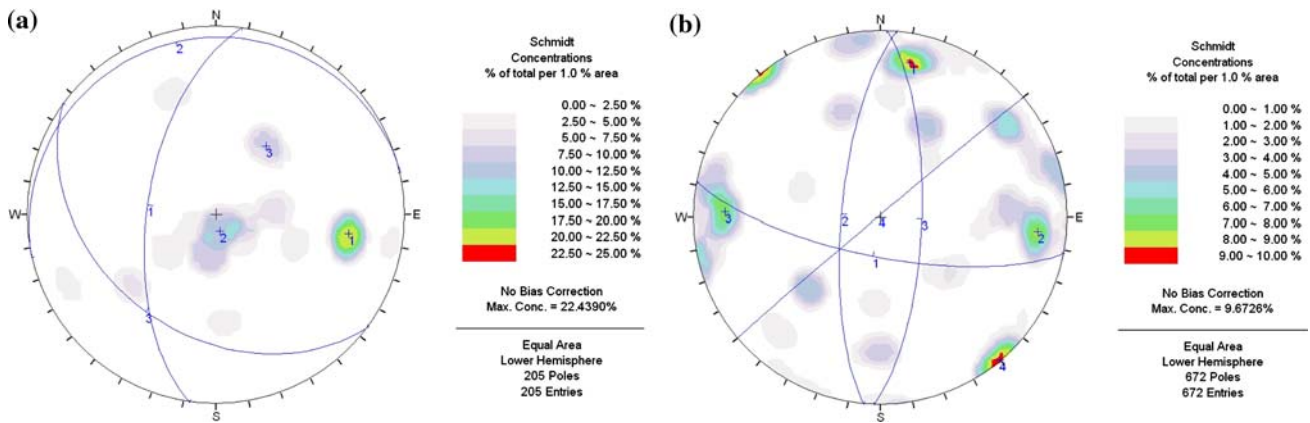


Fig. 6 Contour diagrams and dominant discontinuity sets of the andesite: **a** flow layering, **b** cooling joint

Fig. 7 The variations of the discontinuity spacing in the andesite: **a** flow layering, **b** cooling joint

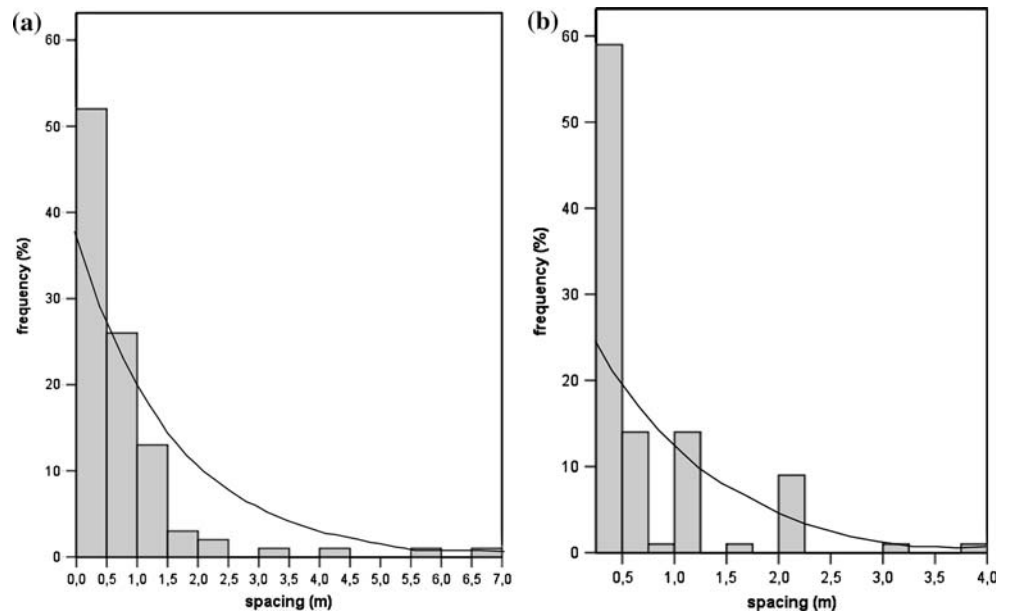


Fig. 8 Photographs showing various sizes of blocks fallen down

close vicinity of the study area (Ulusay et al. 2002; Kocyigit and Ozacar 2003). The area is located within the Second Degree Earthquake Zone of Turkey. Thus, the earthquake vibrations may trigger rockfalls at the Castle.

Engineering geological properties of the andesite

Engineering geological properties of the andesite are evaluated on the basis of field observations and laboratory tests. The samples were subjected to laboratory tests according to ISRM (1981) and TS699 (1987). The tests included determination of index properties of the andesite. The field observations involved the assessment of the rock mass properties. The description of

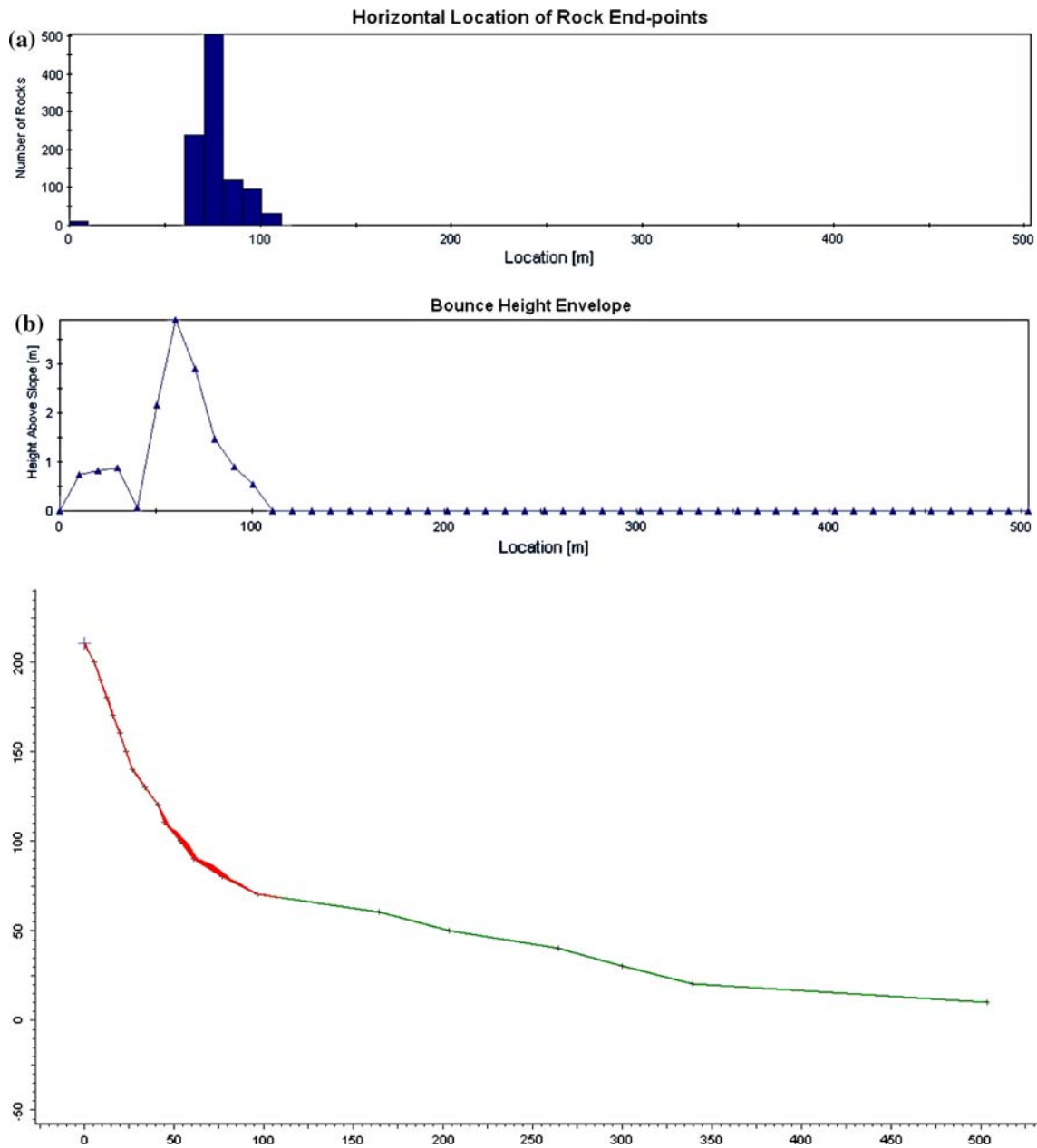


Fig. 9 The variation of **a** fall-out and **b** bounce height of a rock block 10,000 kg in weight

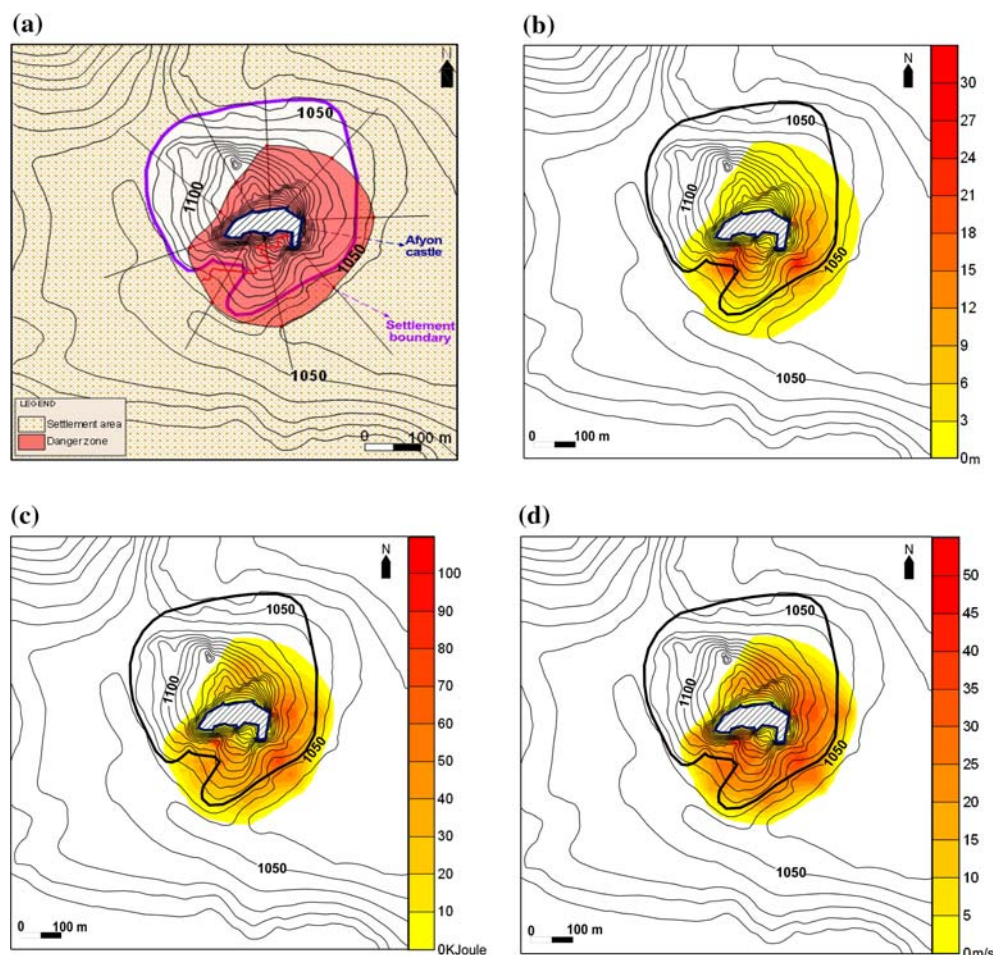
Table 2 Parameters used in the rockfall analysis

Parameters	Value
Coefficient of normal restitution	0.47 ± 0.05
Coefficient of tangential restitution	0.79 ± 0.05
Friction angle (degrees)	40
Slope roughness	2
Initial velocity (m/s)	1 ± 0.5
Number of throws	1,000 rocks
Minimum velocity cut-off (m/s)	0.1
Sampling interval	50

rock material and mass characteristics is based on Anon (1979) and ISRM (1981). The index properties of the andesite are given in Table 1. On the basis of the test results, the andesite is medium strong to strong. It has moderate unit weight, medium porosity and low sonic velocity. There exists about 35% reduction of uniaxial compressive strength due to saturation.

The scanline surveys carried out in the field reveal that the andesite has four dominant cooling joint sets (73/191, 73/245, 72/092, 89/320) and three dominant

Fig. 10 Maps showing **a** fall-out distance, and variations of **b** bounce height, **c** kinetic energy, and **d** velocity during and after rockfalls for 100 kg rocks



flow layering sets (60/278, 07/347, 37/216) (Fig. 6). The discontinuities have very high persistence (>20 m), mainly tight aperture (very wide near the surface). Very wide apertures observed near the surface contain sandy and clayey infilling, but most are free of any kind of infilling. The average spacings of the cooling joints and the flow layering are 0.57 and 0.65 m, respectively. The variations of the discontinuity spacing (Fig. 7a, b) display negative exponential relationship which is in good agreement with Priest (1993). The discontinuity surfaces are generally rough undulating. The andesite is slightly to moderately weathered. No groundwater seepage was noted through the discontinuities in the study area.

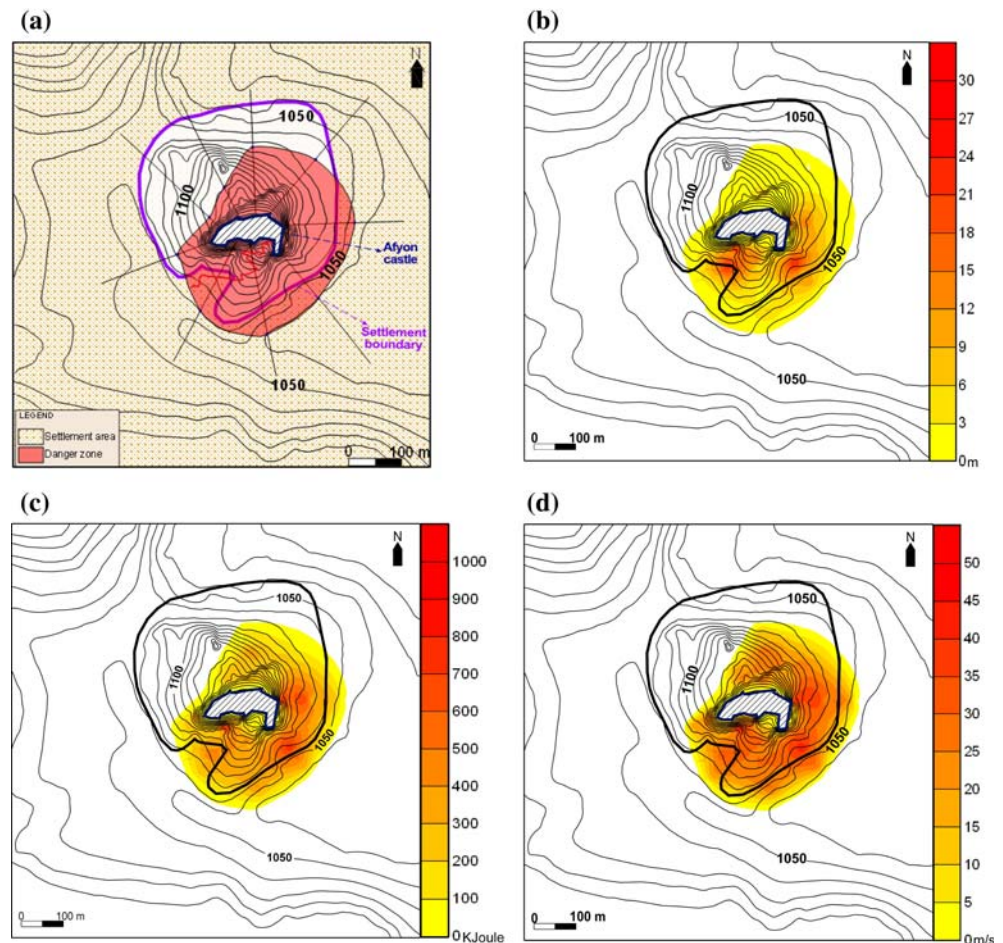
Analysis of rockfall

Field studies performed around the Afyon Castle revealed that there are many blocks of different sizes already fallen down in the past. 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 effect, earthquake tremors, and tree roots are expected to be the main causes of the rockfalls in the study area. The largest fallen block observed is approximately 8 tons (Fig. 8).

For the assessment of the coefficient of restitution of the trachitic andesite, the present positions of the fallen blocks are indicated on the 1:1,000 scale topographic map. The weight of each block is predicted using the volume and the unit weight of the rock. Back analyses for several blocks along three profiles (profile nos. 1, 7 and 8 in Fig. 13) were performed to assess the coefficient of restitution for this site. Additionally, in situ rockfall tests by throwing 27 block samples (each weighing 30–100 kg) were also performed. The in situ tests were carried out along two profiles of an andesitic hill located within close vicinity of the Afyon Castle (about 500 m northwest of the Castle) where the same andesite crops out to avoid any danger to the settlement area during the in situ tests.

Fig. 11 Maps showing **a** fall-out distance, and variations of **b** bounce height, **c** kinetic energy, and **d** velocity during and after rockfalls for 1,000 kg rocks



On the basis of the analysis, the normal and tangential coefficients of restitution of the rocks are found as 0.47 and 0.79, respectively. These and other selected parameters (see Table 2) were used for the rockfall analysis. A typical analysis showing the variation of fall-out distance and bounce height of a block 10,000 kg in weight is shown in Fig. 9a and b. The aerial extents of the fall-out distance, bounce height, kinetic energy and velocity of the rocks along nine profiles by considering blocks of different weights (100–10,000 kg) representing the field conditions are shown in Figs. 10, 11 and 12.

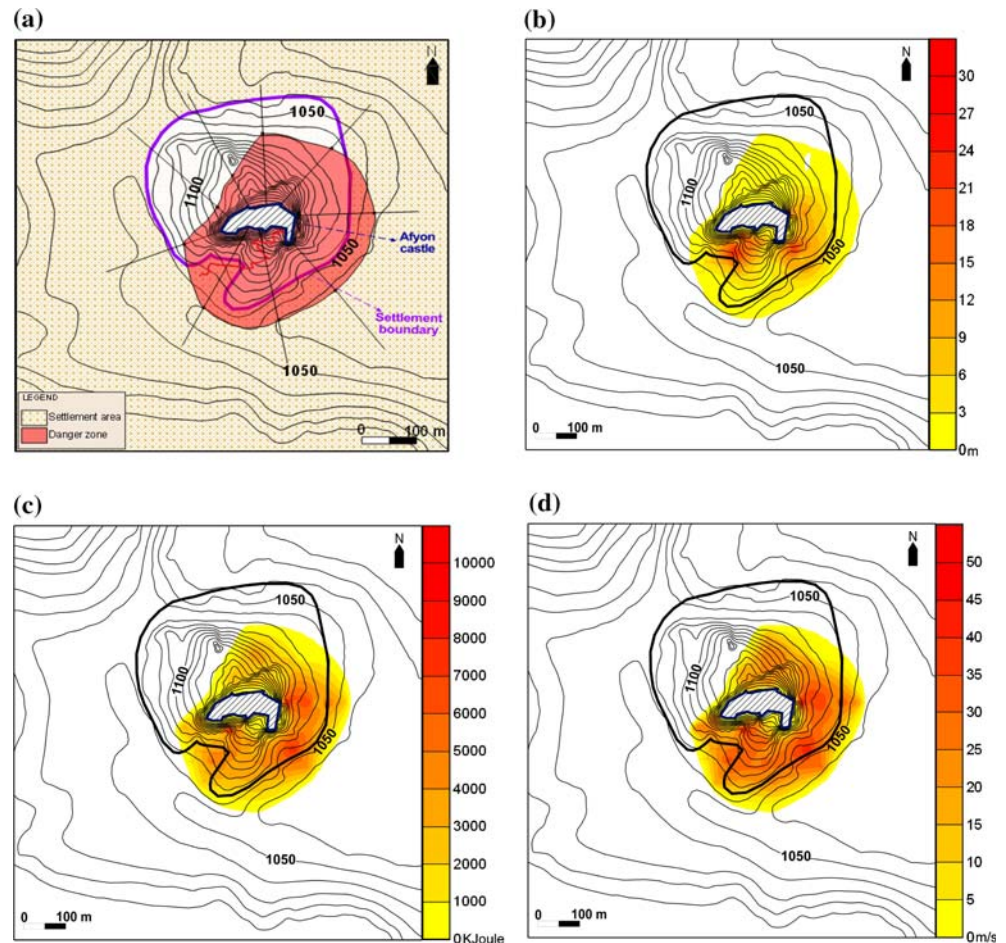
On the basis of the rockfall analyses, the maximum fall-out distance ranges between 40 and 255 m from the source area located just beneath the Castle wall. Bounce height reaches a maximum value of 28 m along the trajectory. On the other hand, maximum kinetic energy is in the order of 9,012 kJ. The blocks attain a velocity of 42 m/s along the trajectory. Although very high kinetic energies, bounce heights and velocities of the blocks are obtained, they decrease with distance 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 without any remedial measures is shown in Fig. 13a. This zone partly involves the settlement areas. The local municipality authorities indicate that there are also several historical buildings located at the southern part of this zone that must be protected. Total evacuation of the danger zone is not preferred by the authorities. Therefore, remedial measures against rockfall hazard are considered. Retaining wall and wiremesh as remedial measures are not preferred either because they 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. They should be removed before adopting any suitable remedial measures. Rock bolting may be applied especially to hold relatively large blocks near the lower levels of the Castle. However,

Fig. 12 Maps showing **a** fall-out distance, and variations of **b** bounce height, **c** kinetic energy, and **d** velocity during and after rockfalls for 10,000 kg rocks



many parts of the hill are difficult to access. Additionally, the existing joints beyond the rock bolts may be separated from the main rock body as the time passes. Although rock bolting may be considered in engineering practice, 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 and the new danger zone after the installation of fences are given in Fig. 13b. The locations are selected such that (a) the fences are between the Afyon Castle and the settlement area if possible, (b) the fences are located where minimum kinetic energy and bounce height are achieved, and (c) the existing pathway for tourists is protected (Fig. 13b). For this reason, protective fences having a maximum height of 6 m and able to resist 3,000 kJ, which is the upper bound of the maximum capacity of the available fences, are expected to stop any potential rockfall in the future. However, the southeastern and eastern parts (along profiles 1, 8 and 9) of the Castle where the danger zone involves the settlement area will be adversely affected from the

rockfall hazard. Therefore, this portion of the area where the protective fence cannot stop the movement due to its limited energy absorbing capacity will be still in danger of rockfall and should be evacuated.

Conclusions and recommendations

There is a potential for rockfall danger in the areas around the Afyon Castle which is located on a hill consisting of trachitic andesite. The rock contains both columnar joints and flow layering which cause freedom for blocks to fall down. On the basis of the field surveys and two-dimensional rockfall analyses along nine profiles around the Castle, it is found that the southern and eastern parts of the Castle are in danger of rockfall. The cleaning of loose blocks, bolting where necessary, and protective fences are suggested for different parts of the Afyon Castle. Although the rockfall risk of the southern part of the Castle can be eliminated with the suggested remedial measures, the southeastern and eastern parts of the Castle where there is still a rockfall danger should be evacuated.

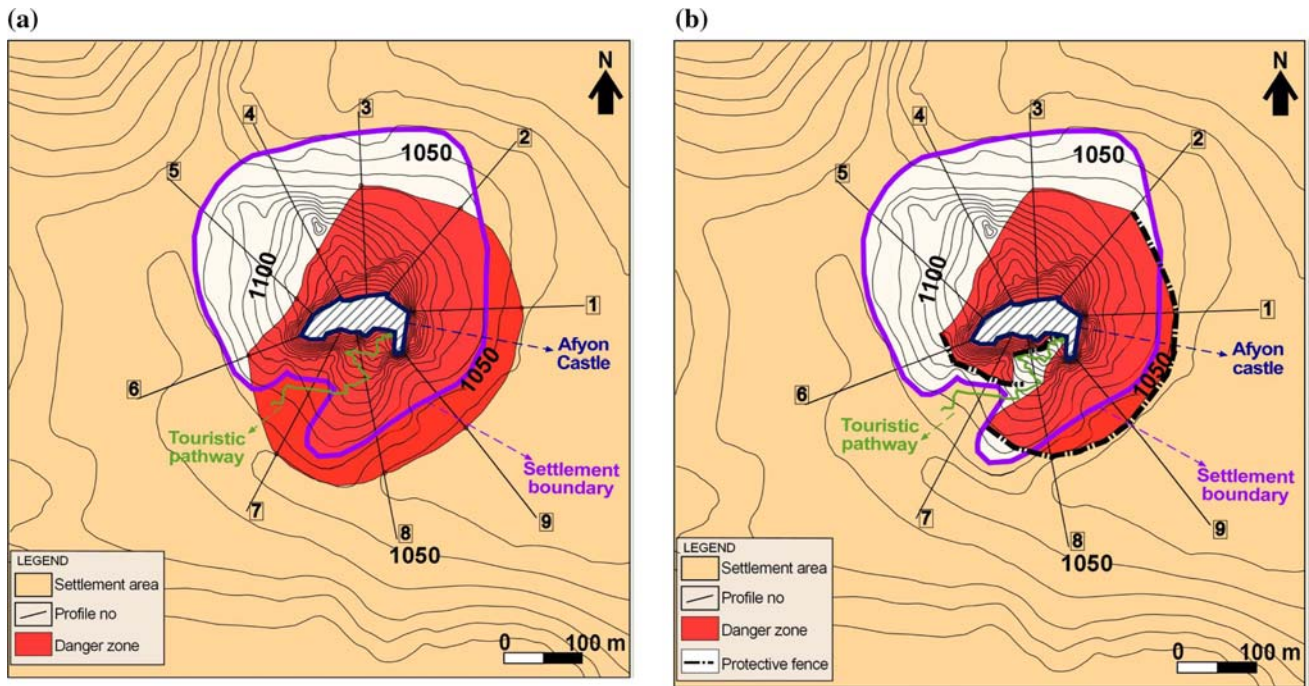


Fig. 13 Map showing the extent of rockfall danger zone around the Afyon Castle **a** before and **b** after the installation of the protective fence as a remedial measure

Acknowledgments This study is financially supported by METU BAP Project (2004-03-09-02). The authors gratefully acknowledge Afyon Municipality, especially Yavuz Unver, Mehmet Guzelkaya, and Hursit Erdogan for their support during the field test, and providing documents related to the Afyon Castle. The authors would also like to express their thanks to the anonymous reviewer(s) of this journal for their constructive comments and suggestions on the manuscript.

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