Rockfall Modelling with Remedial Design and Measures along Part of a Mountainous Settlement Area, Southern Turkey

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Abstract. In June 2011, a heavy rainfall triggered a number of rockfalls from steep slopes and on slopes made of soft to loose soils capped by inhomogeneous hard rock blocks and masses in the Düziçi Town of Osmaniye Province in Turkey. Large rock blocks had damaged 15 prefabricated hotel rooms whereas the slope movement blocked the major road between Düziçi and hot spring facilities at numerous locations along 280 m. This paper describes remedial measures and design recommended according to the modelling process based on the collection of data and simulation of rockfall with Rocscience RockFall 5.0 software.

1. Introduction

Rockfall is one of the most dangerous natural events in mountainous areas. A rockfall is a fragment of rock detached by sliding, toppling or falling that falls along a vertical or sub- vertical cliff, proceeds downslope by bouncing and flying along ballistic trajectories or by rolling on talus or debris slopes [1, 2]. Talus slope deposits at the foot of the hill slope are the indicator of rockfalls. Numerous case studies reported with blocks ranging from a few kilograms to tens of tons cause traffic interruptions, damage to structures and vehicles, and sometimes loss of life. In June 2011, a heavy rainfall triggered a number of rock falls from steep slopes and on slopes made of soft to loose soils capped by inhomogeneous hard rock blocks and masses in the Düziçi Town of Osmaniye Province in Turkey. Large rock blocks had damaged 15 prefabricated thermal hotel rooms whereas the slope movement blocked the major road between Düziçi and hot spring facilities at numerous locations along 280 m (Figure 1). The slope was about 300 m high and had been cut about 70 degrees in moderately weathered fractured recrystallized limestone and talus-colluvium type materials at the toe of the slope along a fault zone.

Figure 1. Rockfall damage at the study area

2. The study Area

2.1. Geology

The study area and a large part of its immediate vicinity are composed of Jurassic-Cretaceous aged limestone and dolomitic limestone units. Rock mass generally had close spacing and was characterized as medium strong and weak rock. Furthermore, it is tectonically placed over a fault fracture zones with related potential for loose talus and colluvium type materials originated by faulting mechanism. The thickness of the rock talus is up to 15-20 m at the toe of the slope. Diabase dikes, metagabbro and some igneous rocks such as serpentine are also located in the near field. Rapid erosion of the bed of the Ceyhan River causes fairly steep natural slopes with instability problems, such as rockfalls. The slope was about 300 m high and had been cut about 70 degrees in moderately weathered fractured recrystallized limestone and colluvium type materials at the toe of the slope along a fault zone.

2.2. Rockfall Mechanism

Rockfall mechanism can be quite complex. Slope geometry, material properties and rock locations are the most important parameters before an analysis has been carried out. Energy, velocity and bounce-height mean, standard deviation, and maximum energy are assessed along the slope profile which can be selected from the study area. The most important factor in determining the trajectory of a falling rock is the slope geometry. Especially in very steep slope surfaces, the horizontal movement component occurs as a result of bouncing of rolling or falling rock blocks. Those surfaces are playing a very dangerous role such as ski jump, and falling rocks are gaining a very high horizontal velocity, causing the leap to a more distant point of the toe from sliding hillsides. Strong fresh or unweathered clean steep rock surfaces have a high risk, due to the giving a high acceleration for the falling or rolling rock boulders. On the other hand, the materials on surfaces such as gravel or scree, absorbed the energy of falling or rolling rocks significantly, and in many cases they cause complete stoppage of the block.

3. Back Analysis of Rockfall

3.1. Modelling

Rockfall analysis was modelled by means of using simulation techniques. Three geologic cross section of hillside, were used for the back analysis (Table 1 and Figures 2 & 3). Field inspection of slope material failed indicated that the slope had high water content at the time of movement because of rainy periods and hot spring supplies. Two berms, called lower and upper, were created just before the rockfall instability problem.

Table 1. Properties of the geological sections

	Start	End	Start	End
	X(m)	Y(m)	X(m)	Y(m)
Section 1	273386	4138689	273386	4139049
Section 2	273457	4138703	273457	4139063
Section 3	273581	4138863	273487	4139051
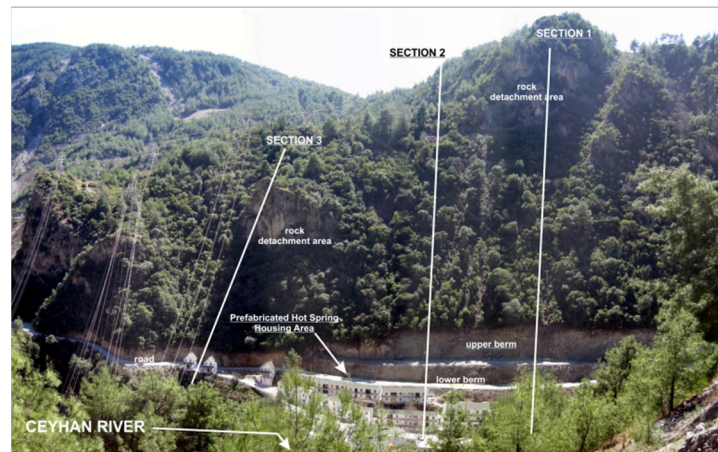
Figure 2. A general view of the study area, looking south
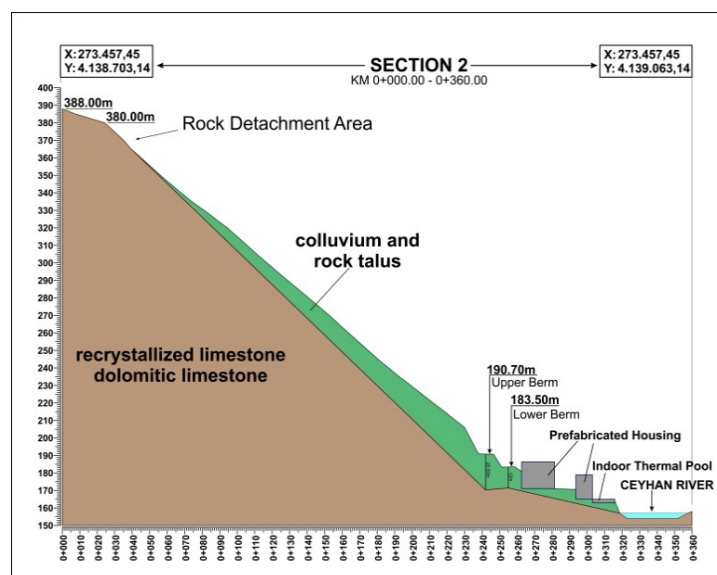
Figure 3. General path of the section #2

3.2. Analysis Method

Rockfall risk analyses were carried out with Rocscience software called RockFall Ver. 5.014 [3]. RocFall is a statistical analysis program designed to assist with assessment of slopes at risk for rockfalls. Energy, velocity and "bounce height" envelopes for the entire slope are determined by the program, as is the location of rock endpoints. Distributions of energy, velocity and bounce height are also calculated along the slope profile. Distributions can be graphed and comprehensive statistics are automatically calculated.

3.3. Coefficient of Restitution

The major parameter used in the rockfall simulation models is the coefficient of restitution with two components (Normal coefficient of restitution Rn, Tangential coefficient of restitution Rt). The parameter determines the energy loss of falling rock during a rebound on the slope surface. Various restitution coefficients used in analysis are given in Table 2 and they are explained in Rocscience manual [3].

Table 2. The used parameters for the coefficient of restitution

| Surface Type	Normal Rn		Tangential Rt	
	Mean	SD*	Mean	SD*
Rock Surface	0.530	0.040	0.990	0.040
Rock Talus	0.320	0.040	0.820	0.040
Wood platform	0.384	0.133	0.687	0.130
Asphalt	0.384	0.133	0.687	0.130
Concrete	0.480	0.190	0.530	0.170

*SD: Standard Deviation

3.4. Results of Analysis

Based on the rockfall analysis, various bouncing heights of rock boulders or blocks were determined. The analysis focused on the rock catchment barrier according to the bounce height of the rock (Table 3 and Figure 4). Two different rock mass were selected for the back analysis of the rockfall case history. The minimum rock weight was 10 kg, while the maximum was 100 tons. These values were determined based on field observations.

Table 3. Parameters for the design of catchment barrier

	Most probable total kinetic energy (kJ-%)	Max probable total kinetic energy (kJ-%)	Most probable bounce height after hit first barrier (m-%)	Max probable bounce height after hit first barrier (m-%)
SECTION # 1				
10 kg Rock Boulder	0.60 kJ - %18	1.01 kJ - %0.5	1.41 m - %33	2.00 m - %1
100 ton Rock Block	6484 kJ - %8	9710 kJ - %0.5	1.51 m - %51	2.10 m - %1
SECTION # 2				
10 kg Rock Boulder	0.95 kJ - %22	1.31 kJ - %1	0.30 m - %45	0.70 m - %9
100 ton Rock Block	8694 kJ - %15	13641 kJ - %1	0.30 m - %48	0.70 m - %7
SECTION # 2				
100 ton Rock Block	917 kJ - %21	3002 kJ -%7	0.20 m - %79.41	1.00 m - %5.88
SECTION # 3				
10 kg Rock Boulder	0.60 kJ - %23	0.74 kJ - %1	0.50 m - %31	0.90 m - %5
100 ton Rock Block	5963 kJ - %23	7884 kJ - %1	0.50 m - %31	0.90 m - %1
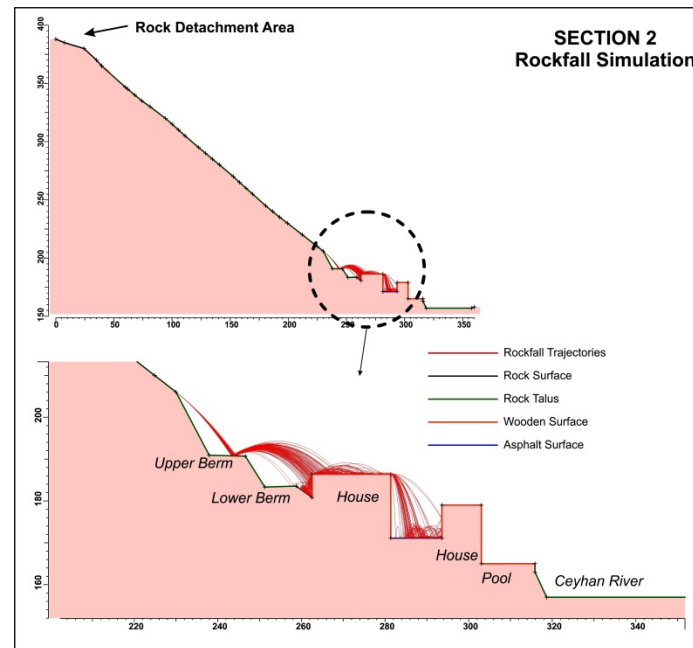
Figure 4. RockFall simulation of the section #2

These results suggest that among certain limits, protective and rock catchment barriers could be constructed on the berms. The kinetic energy of a barrier with height of 4.0 m could have a resistant up to 5000 kJ. Barrier specifications will be designed in accordance with the European Technical Approval Guidelines (ETAG), such as deformable barriers. First absorption of the kinetic energy of the bouncing rock boulders or blocks will be held by the free damping uncompacted gravel at least 30 cm thick on the upper berm. Simple design of rockfall barrier based on 5000 kJ is shown in Figure 5.
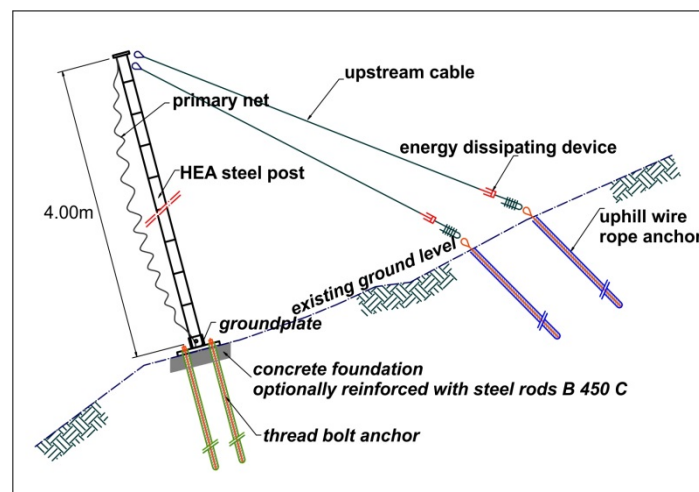
Figure 5. Simple design of rockfall barrier based on 5000 kJ (barrier draw was reproduced from [4])

4. Conclusions

A back analysis of rockfall case history of various parameters was described and determined from field inspections. The rocks were moderately weathered fractured recrystallized limestone and rock talus with colluvium type materials at the toe of the slope along a fault zone. In some weak rocks tensile fractures apparently formed due to interaction of considerable water flow along out-wash discontinuity surfaces

with the free face of the steep valley slopes. Rock mass generally had close spacing and was characterized as medium strong and weak rock. During the rainfall, a number of boulders, some as large as 100 tons in mass, broke loose and fell, rolled, or bounced down the ridge flank. Some of them came to rest on the prefabricated houses and roadway to the Düziçi town. Field inspection of slope material failed indicated that the slope had high water content at the time of movement because of rainy periods and hot spring supplies. The maximum weight of the rock block was the most important significant parameter when designing the rock catchment barriers. Very high kinetic energies were resulted from the back analysis such as 13 641 kJ. However, for more economical design, the high kinetic energy can be reduced with granular based material with clean gravels. The thickness of the free uncompacted gravel material can reduce the height of the rockfall barrier. The rockfall protection barrier is therefore designed in accordance with a kinetic energy of 5000 kJ having a height of 4.00m.

References

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