Rockfall Analyses at Km 13+550 in the New Road of Vlora, Albania

Arjol Lule

Ph.D. Student, Department of Applied Geology,
Environment and Geo-Informatics, Faculty of
Geology and Mining, Polytechnic University of Tirana

Abstract

Rockfall dynamics is a complex function of the location of the detachment point and the geometry and mechanical properties of both the block and the slope. Theoretically, knowing the initial conditions, the slope geometry, and the relationships describing the energy loss at impact or by rolling, it should be possible to compute the position and velocity of a block at any time. Nevertheless, relevant parameters are difficult to ascertain both in space and time, even for an observed event. Usually, the geometrical and geomechanically properties of the blocks (size, shape, strength, fracturing) and the slope (gradient, length and roughness, longitudinal and transversal concavities and convexities, grain size distribution, elastic moduli, water content, etc.), and the exact location of the source areas are unknown. In this paper, the sources of potential rock fallings involve a rocky area including between km 13+550 and km 13+600 in the new road of Vlora city in Albania. The area is characterized by a rock ridge, shaped like a dome, located few tens of meters above the design road. The purpose of this paper is the rock slope analysis. This analysis consists mainly of defining the sources of falling rocks, estimating the causes (by toppling, rock slides, single blocks) the size, the geometry, and type of blocks, the structural arrangement of joints, etc.

Keywords: Rocks slopes analysis, geomechanically.

Introduction

Rockfall phenomena start by the detachment of blocks from their original position. This phase is followed by free-falling, bouncing, rolling, or sliding, with falling blocks losing energy at impact points or by friction. Kinematic, dynamic, or empirical equations can be used to model rockfall processes and define regions subjected to this hazard. Rockfall dynamics is a complex function of the location of the detachment point and the geometry and mechanical properties of both the block and the slope. Theoretically, knowing the initial conditions, the slope geometry, and the relationships describing the energy loss at impact or by rolling, it should be possible to compute the position and velocity of a block at any time. Nevertheless, relevant parameters are difficult to ascertain both in space and time, even for an observed event. Usually, the geometrical and geomechanically properties of the blocks (size, shape, strength, fracturing) and the slope (gradient, length and roughness, longitudinal and transversal concavities and convexities, grain size distribution, elastic moduli, water content, etc.), and the exact location of the source areas are unknown. The same can be said for the variability of the controlling parameters. Also, the energy lost at each impact or during rolling depends on a variety of factors including the velocity of the block and the impact angle, the block to slope contact type (block corner, edge or face), and the presence and density of vegetation. These parameters are difficult to quantify both precisely and accurately at any spatial scale. Thus, "contact functions" relating the block kinematics (in terms of velocity) or dynamics (in terms of energy) before and after the impact, are introduced to model the energy loss at each impact point. Such functions are usually expressed as restitution and friction coefficients and regarded as material constants even if, as already mentioned, they include the effects of many different controlling factors (type and thickness, texture and structure of slope deposits, block size and geometry, angle and velocity of impact, the geometry of the impact, vegetation, soil moisture content, etc.). (G. B. Crosta, F. Agliardi., 2003,). Then, performing a rockfall analysis consists mainly in:

defining the sources of falling rocks, estimating the causes (by toppling, rock slides, single blocks) the size, the geometry and type of blocks, the structural arrangement of joints, etc.

estimating (statistically) the rockfall trajectories and interference with the existent and the design structures (hazard and risk estimate) estimating and dimensioning rockfall protections based on points a) and b) and level of risk requested. Rocks slopes collapses are in general difficult to predict, meaning "difficult to predict with precision when and where will occur a collapse event". Statistically, the probability of occurrence in someplace and the probability, or most probability, how it will occur, can be predicted even if every analytical, empirical and mechanical model approach can't be as near reality as variability of natural conditions and 'discrete' conditions of rock masses. Risks on rock masses stability are usually higher than soils; this depends on the velocity of the evolution of the instability event. In rock masses, the time from the activation and its development is quite short, and the results are catastrophic.

Methodology

The study has been carried out mainly by acquiring and interpreting data on outcrops but also data from satellite images. Detailed information was acquired in the field. The area is extremely complex from the structural point of view. During the fieldwork, every measurement, observation, description, samples, and interpretation made were recorded both in a pocket PC and in a papery notebook. The location of every record/data was recorded with GPS instruments to be able to trace the exact location of the object or information desired. Typical working equipment used during fieldwork activity were: metric tape); steel nails to fix the tape extremities; cameras for pictures); field register to record measurements; traditional geological compass and hammer; rock marker.

Figure 7. Working equipment

The general approach in the field was:

to choose a continue representative fractured bed (faulted or not

to describe the outcrop (lithology, facies, orientation, strata thickness, take a picture…);

to collect data and to observe details

Results and discussion

The sources of potential rock fallings involve a rocky area including between km 13+550 and km 13+600. The area is characterized by a rock ridge, shaped as a dome, located few tens of meters above the design road. With the help of aerial satellites, which provide images of rock crests and unstable boulders from where rocks could fall, rockfalls area have been marked in the figure 2.

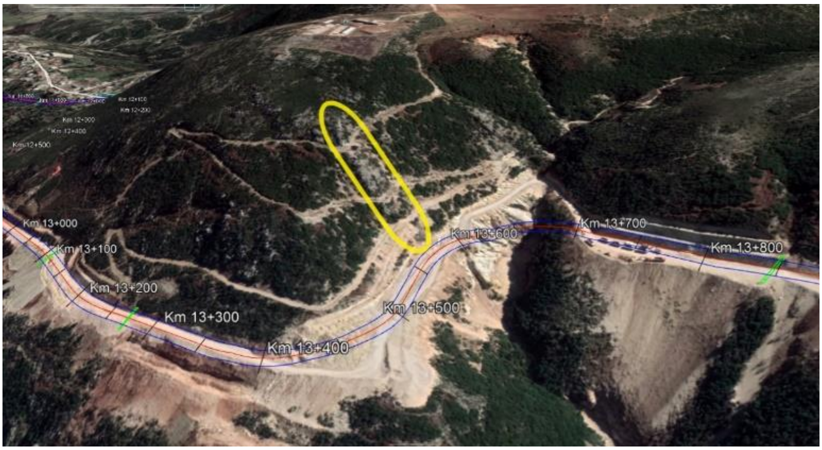


Figure 8. Satellite view of the area: in yellow the source area of potential rockfalls

Figure 9. Orientation of the main joint sets.

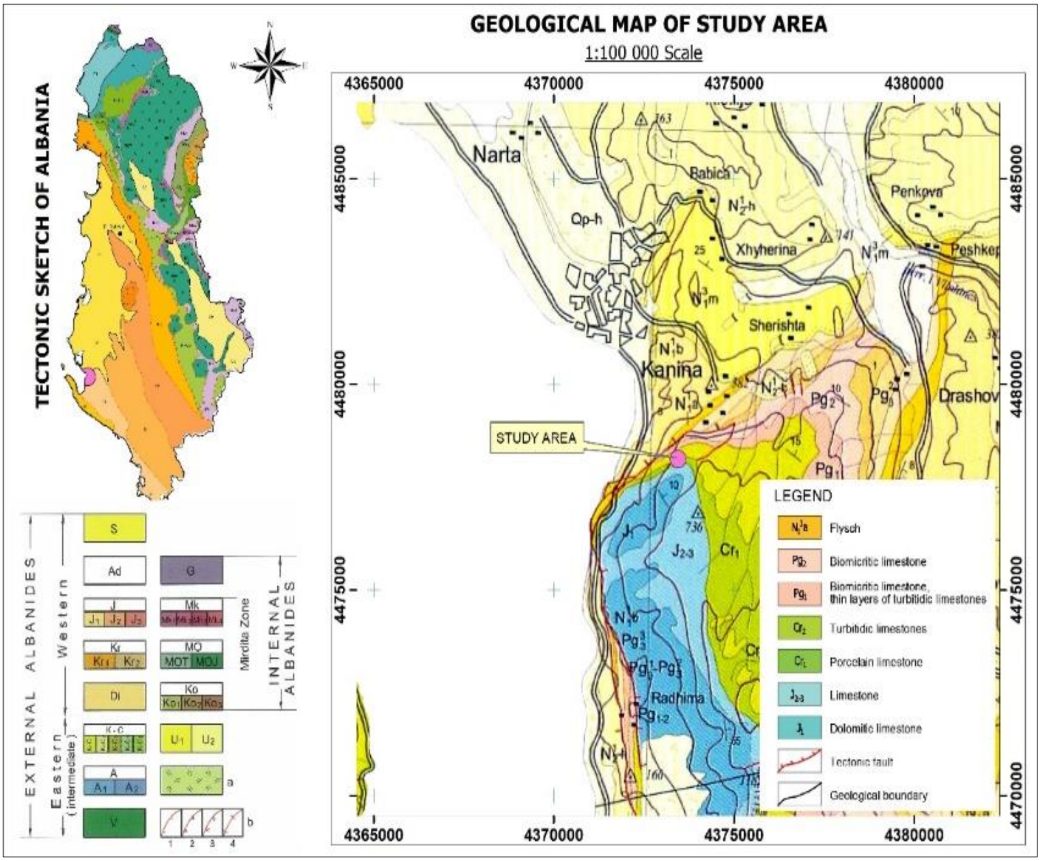
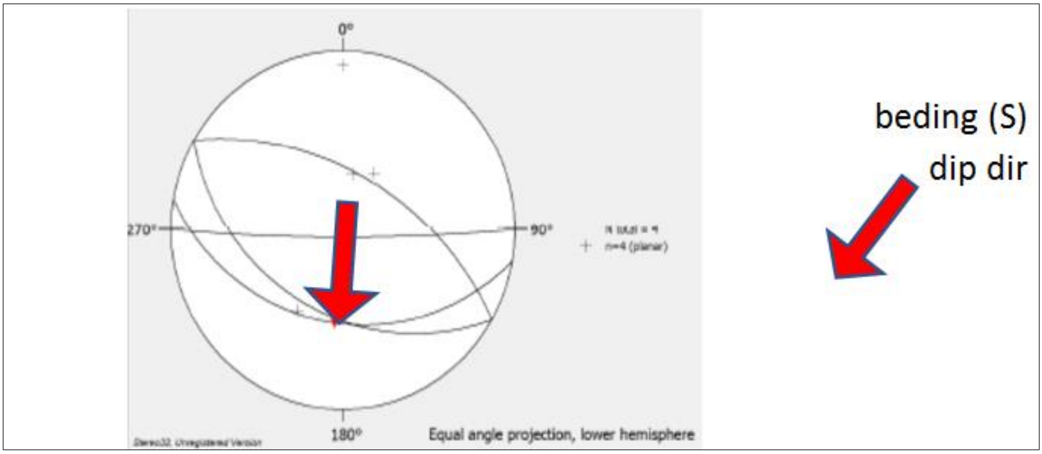


Figure 10.Geological map



Gemechanical survey 1 -GM1					
NOTE					
SMITH HAMMER REBOUND: 30					
DIP DIRECTION / DIP ANGLE					
S	19035	210/40	overtuned?		
K1	180/85				
K2	30/55				
K3					
SPACING (cm)					
S	2-15				
K1	20-50				
K2	100-300				
K3					
LINEAR PERSISTENCE(%)- AREAL PERSISSTENCE(%)					
PL<50	50 ≤PL<90	PL≥90			
PA<20	20 ≤PA<90	PA≥91			
SHAPE					
PLANAR	UNDULATING	SEGMENTED	IRREG.		
WEATHWRING DEGREE					
WD1	WD2	WD3	WD4		
APERTURE(mm)					
CLOSED	<1	1<A<2.5	2.5<A<5.0	>6	
INFILLING					
ABSENT	GRANULAR	COHESIVE	RECRIST		
MOISTURECONDITION					
MPOSS	DRY	DAMP	WET	DROPSWATER	CONTINUOS FLOW
ROUGHNESS					
S	K1	K2	K3		
6-8	0-2	10-12			

Figure 11. Geomechanical records in station GM.1

By means of the geomechanical survey it is possible to determine the variation range of the the geological strength index (GSI) is a system of rock mass characterization that was developed, by (Hoek, (1994),) and (E. Hoek, P.K. Kaiser, W.F. Bawden, 1995), to link the failure criterion to engineering geology observations in the field. On the base of available data, estimation analyses are performed. Most of the multi-parameter classification schemes (Wickham, 1972) (Bieniawski, Z.T., 1973) and (Barton, 1974) were developed from civil engineering case histories in which all of the components of the engineering geological character of the rock mass were included. Geological Strength Index of classification GSI considering that, according to the inspection, the volume of the representative rock blocks should be from 125 dm3 up to 0.5 m3. Considering the block volume V_b, and according to the following tables (Palmstrom, 1995) with the ratings for the large-scale waviness J_w, small scale smoothness J_S and joint alteration condition J_A, the resultant value of the joint condition factor can be found as:

$$J_C = \frac{J_W \; x \; J_S}{J_A}$$

Table 5. Terms to describe large scale waviness

Waviness terms	Undulation	Rating for waviness J_W
Interlocking (large-scale)		3
Stepped		2.5
Large undulation	>3%	2
Small to moderate undulation	0.3–3%	1.5
Planar	<0.3%	1

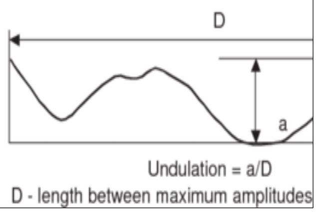


Table 6. Terms to describe small scale smoothness

Smoothness Terms	Description	Rating for Smoothness J_S
Very rough	Near vertical steps and ridges occur with interlocking effect on the joint surface	3
Rough	Some ridge and side-angle are evident; asperities are clearly visible; discontinuity surface feels very abrasive (rougher than sandpaper grade 30)	2
Slightly rough	Asperities on the discontinuity surfaces are distinguishable and can be felt (like sandpaper grade 30 - 300)	1.5
Smooth	Surface appear smooth and feels so to touch (smoother than sandpaper grade 300)	1
Polished	Visual evidence of polishing exists. This is often seen in coating of chlorite and specially talc	0.75
Slickensided	Polished and striated surface that results from sliding along a fault surface or other movement surface	0.6-1.5

Table 7. Rating for the Joint Alteration Factor

Term		Description	J_A
	Clear joints		
Rock wall contact	Healed or "welded" joints (unweathered)	Softening, impermeable filling (quartz, epidot, etc)	0.75
	Fresk rock walls (unweathered)	No coating or filling on joint surface, except for staining	1
	Alteration of joint wall: slightly to moderately weathered	The joint surface exhibits one class higher alteration than the rock	2
	Alteration of joint wall: highly weathered	The joint surface exhibits two classes higher alteration than the rock	4
	Coating or thin filling		
	Sand, silt, calcite, talc, etc.	Coating of frictional material without clay	3
	Clay, chlorite, talc, etc.	Coating of softening and cohesive minerals	4
Filled joints with partial or no contact between the rock wall surfaces	Sand, silt, calcite, etc.	Filling of frictional material without clay	4
	Compacted clay materials	"Hard" filling of softening and cohesive materials	6
	Soft clay materials	Medium to low over-consolidation of filling	8
	Swelling clay materials	Filling material exhibits swelling properties	8-12

For:

$$V_b = 125\ dm^3$$

$$J_W = 1.5$$

$$J_S = 1.5$$

$$J_A = 4$$

$$J_C = \frac{1.5\ x 1.5}{4} = 0.5625$$

and for the relationship that links the joint condition factor and the block volume to the GSI (Cai, M. & Kaiser, P.K., 2006)

$$GSI = \frac{26.50 + 8.79\ \ln J_C + 0.90\ \ln V_b}{1 + 0.0151\ \ln J_C - 0.025\ \ln V_b}$$

the GSI resulting value, where V_b must be in cm3, is:

$$GSI = \frac{26.50 + 8.79\ \ln 0.5625 + 0.90\ \ln 125000}{1 + 0.0151\ \ln 0.5625 - 0.025\ \ln 125000} = 36$$

For:

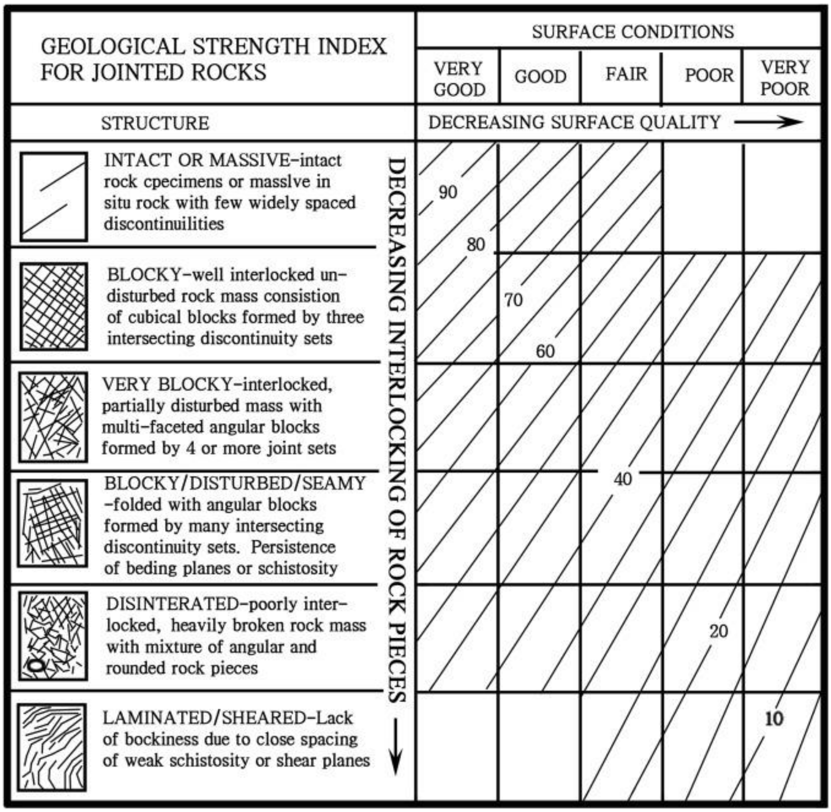
$$V_b = 500\ dm^3$$

and the previous values of the remaining parameters for waviness, smoothness, alteration, and joint condition factor, the GSI resulting value becomes:

$$GSI = \frac{26.50 + 8.79 \ \ln 0.5625 + 0.90 \ \ln 500000}{1 + 0.0151 \ \ln 0.5625 - 0.025 \ \ln 500000} = 40$$

In the GSI chart, the previous values of GSI point out that rock masses have structure passing from blocky to blocky and folded.

Table 8. GSI as a function of JC and Vb (Bieniawski, 1989)



Respect to the rockfall problem, the GSI classification underline that, even blocks of more than a cubic meter can be visible on the rock slope, the joints pattern pertains to isolated blocks having a moderate volume not exceeding 0.200 m3.

Block volume (Vb)				
Very small	*Small*	*Medium*	*Large*	*Very large*
10-200 cm3	*20-10 dm3*	*10-200 dm3*	*20-10 m3*	*> 10 m3*

An assessment of the potential rockfalls has been carried out for the source area above the road stretch near km 13 + 550. This area is characterized by potentially unstable blocks with a volume up 2 m^3 that could reach the design road located below.

Comparing the obtained results, underlining that the results of the 2 m equivalent diameter, corresponding to a block volume greater than 4 m^3, are considered not representative of a probable rockfalls, because similar blocks should break apart during the impacts along their path, a rockfall barrier is suggested to protect the traffic along the road in the stretch from km 13+550 to km 13+600. The rockfall barrier must be placed uphill of the road.

Figure 12. Rockfall barrier- km 13+550

Conclusion

The assumptions on the ground where the barrier will be founded are based on preliminary investigations. More detailed topographical and geotechnical-geomechanical surveys are needed to properly design the rockfall barrier requested to put in safety conditions the road stretch herein examined. Therefore, in the drawing of figure 6, the disposition of the requested rockfall barriers is just an indication and must be properly evaluated and checked before the start of the works.

References

[1] Barton, N. L. (1974). Engineering classification of rock masses for the design of tunnel support. Rock Mech. 6(4), 189-239.
[2] Bieniawski, Z. (1989). Engineering rock mass classification. New York: Wiley Interscience.
[3] Bieniawski, Z.T. (1973). Engineering classification of jointed rock masses. Trans S. Afr.Inst. Civ. Engrs 15,, 335-344.
[4] Cai, M. & Kaiser, P.K. (2006). Visualization of rock mass classification systems. Geotech Geol Eng, 24(4), .

[5] E. Hoek, P.K. Kaiser, W.F. Bawden. (1995). Support of underground excavations in hard rock. A.A. Balkema, Rotterdam.
[6] G. B. Crosta, F. Agliardi. (2003,). G. B. Crosta, F. Agliardi. A methodology for physically-based rockfall hazard assessment. Natural Hazards and Earth System Science, Copernicus Publications on behalf of the European Geosciences Union, 3 (5), , pp.407-422.
[7] Hoek, E. ((1994),). Strength of rock and rock masses , 2 (2). ISRM News Journal, pp. 4-16.
[8] Palmstrom, A. (1995). RMi—A Rock Mass Characterization System for Rock Engineering Purposes. . Oslo, Norway,: Ph.D. Thesis, University of Oslo, .
[9] Wickham, G. T. (1972). Support determination based on geologic predictions. North American rapid excav. tunneling conf., , (eds K.S. Lane and L.A. Garfield) (pp. 43-64). Chicago: New York: Soc. Min. Engrs, Am. Inst. Min.