Rock Fall Simulation – A State of The Art Tool for Risk Assessment and Dimensioning of Rockfall Barriers

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Abstract

Within this paper actual experiences using a commercially available computer program ROCKFALL 6.0 are presented. The advantages as well as some actual shortcomings of rockfall simulation are discussed. An example of rockfall mitigation measures for a Japanese railway line designed on the base of a rockfall simulation is presented.

Introduction

In December 1999 a revised edition of the German Railways Standard Ril 836 on the design and maintenance of rock and soil structures came into force. For the first time rules for the design of modern rockfall protection works had been set within a German standard. It recommends to determine the suitable location, the necessary height and the required energy consumption capacity on the base of field tests or by a computer simulation.

By this recommendation a design tool has gained the status of an accepted technical rule, which has gradually replaced the often expensive and statistically ambiguous rockfall tests. Rockfall simulation not only can support the design of rockfall barriers, but also proved as a valuable tool for the assessment of rockfall risks.

There are different approaches to rockfall simulation. They differ considerably as for their theoretical background and their applicability. GIANI (1) distincts rigorous and lumped mass methods. In the rigorous method analysis, the size and shape of the blocks are assumed and all the block movements, including those involving block rotation, are considered. In the lumped mass method, the single block is reduced to a mass point. The angular velocity is not considered.

Rockfall simulation

Within this publication a commercially available rockfall simulation program ROCKFALL 6.0 was used belonging to the rigorous method category. It allows for the consideration of spherical and cylindrical rocks. The rockfall paths are calculated in two dimensional sections. All relevant surface and rock block data are considered. Up to 10.000 rocks can be simulated by a single run. The results can be analyzed by a wide range of different statistics. Barriers can be installed at any location. A detailed description of its basics and potential is given by SPANG (2).

Compared to the historical and the empirical approach, as described by SPANG (3) rockfall simulation has considerable advantages. The historical approach assumes no rockfall risks at locations, where rockfall never had been observed. Thus neither deterioration of stability conditions nor new slopes can be assessed. The empirical approach relies on rockfall tests, which might endanger the structures to be protected or require the interruption of traffic lines. In most cases the number of rocks rolled is not sufficient to get statistically reliable results. In contrast Rockfall simulation is always applicable, quick and reproducible. ROCKFALL 6.0 allows for extensive parametric studies. It can be combined with the historical approach and can evaluate rockfall tests on a sound scientific base. It is able to assess rockfall risks as for their reach and give all parameters necessary for the selection of appropriate locations, energy consumption and required height of rockfall mitigation measures. Even the influence of forests can be considered and loading of rockfall sheds determined. The extensive statistical output can be used for modern probabilistic approaches to safety.

Actually there are a lot of experiences as for the selection of appropriate slope surface and rock block parameters required by the simulation (SPANG & SÖNSER) (4). These experiences cover a wide range of different rock, soil and vegetation conditions, but there are no field or laboratory tests available to determine these parameters. This makes it difficult for inexperienced designers to come to realistic input data. There are strong efforts to extend the program to polygonal rockfall geometries within the near future. Because of the high cost for reliable three- dimensional topographic surveys a three-dimensional version seems not to be helpful within the next years. The above described advantages of rockfall simulation will be illustrated by the following example.

Koumi Line, Japan

Some 180 km northwest of Tokyo, near Nagano, the Koumi Line of Japan Railways connects a well known leisure area to Japan’s main cities. It mainly serves for passenger transportation. Between km 43.570 and 43.970 the single track railroad runs on the right slope of a steep and narrow gorge of the Chikumagawa river. The slope extends about 50 m above the railway line and shows an average inclination of 35 degrees. It is topped by a 80 m high nearly vertical rock wall built up by andesite, chert, sandstone and slate. The rock quality is affected by a major active fault zone crossing the island of Honshu northwest-southeast.

The track runs at an altitude of about 1.000 m a.s.l. The region is affected by an average of 1.400 mm of annual rainfall including events up to 200 mm/day. During 2 months of the year temperatures fall below zero degree.

The rock surface shows a lot of open joints. Fresh impacts on trees and on the slope surface below the rock wall, as well as fresh to recently fallen rock blocks with volumes up to 3 m^3 on the slope surface proved a serious rockfall risk. Daily rockfall events were supposed to have volumes smaller than 0.1 m^3, ten year events smaller than 3 m^3 and century events up to 200 m^3.

Existing Rockfall Mitigation Structures

To protect the railroad JR had taken several conventional rockfall mitigation measures since long. Some 30 m from the track a rockfall barrier had been installed with a height of 1.5 m, consisting of vertical rails with concrete footings and two horizontal steel beams with panels of steel wire mesh between. It had been destroyed by rockfall at several locations and provisionally repaired by wooden lagging. The state of this structure was generally bad. It had been partly filled by small scale rockfall, leaves and branches. The steel members showed considerable corrosion. Obviously the structure was to low and not strong enough. Its energy consumption capacity was assessed to be lower than 50 kJ (SPANG & SÖNSER, 4).

Some meters above the track a second rockfall barrier had been installed. It consisted of 5 m high inclined steel beams supported by spanning members. Both had concrete footings. The beams were connected by horizontal steel ropes covered by steel wire mesh. Additionally the track was protected by a rockfall gallery, consisting of steel frames with steel spreaders. The lagging was made from steel panels with a thin soil cover on top. No damages could be seen. The height of the former seemed to be sufficient, the energy consumption capacity of both structures was assessed to be about 100 to 150 kJ.

Input data

In a first step the existing structures had to be finally assessed and if required, the location, height and energy consumption of additional rockfall mitigation measures had to be determined. This assessment was done by ROCKFALL. Input data are shown by table 1. The variation considers the degree of uncertainty in the determination of the specific parameter.

No.	Parameter	Dimension	Surface type			
			1		2	
			mean	variation %	mean	variation %
1	Static friction	°	40	10	35	10
2	Dynamic friction	°	30	10	25	10
3	Normal damping	/	0,03	10	0,015	10
4	Tangential damping	/	0,9	10	0,87	5
5	Rolling Resistance	/	0,08	10	0,15	10
6	Roughness-amplitude	m	0,1	/	0,2	/
7	Roughness-frequency	m	1,0	/	1,0	/
8	Mass	kg	6,347			
9	Geometry	‘/	sphere			

Table 1: Input data; surface types: 1 rock surface, uneven; 2 debris cone, scarcely wooded

Results

Fig. 1 shows the slope profile and the paths of 1.000 rockfalls, calculated on the base of the above mentioned input data. The detachment zone of rockfalls stretched from behind the crest down to the toe of the rock face. The exact location for each rock within this zone was given by a random number generator. 997 rocks hit the planned 4 m high inclined new barrier at x = 115 m, 3 failed. The existing rockfall barrier would have caught a rather smaller number of rocks.

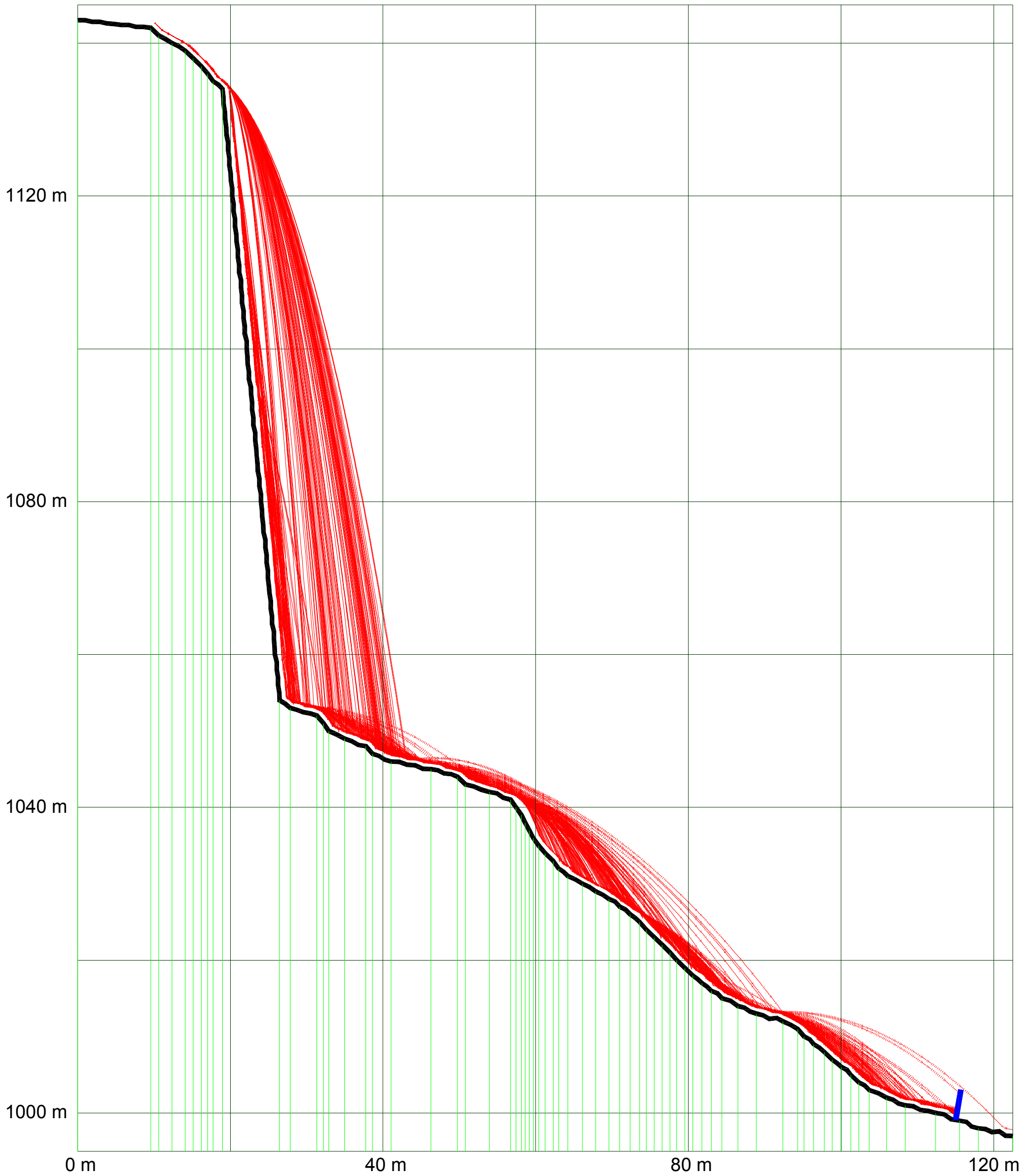

Fig. 1: Slope profile and rockfall paths by ROCKFALL 6.0

The most important numerical results are summarized in table 2, whereas table 3 shows their statistical analysis and graphical representation. The diagrams 1 and 2 represent the distribution of the kinetic energy and the bounce height along the profile. The following diagrams show the distribution of the indicated parameters at the moment of impact in the axis of the new barrier.

No.	Parameter	Dimension	min.	max.	mean	standard deviation
1	Required barrier height	m	0,83	5,77	0,98	0,22
2	Total energy	kJ	31	2.512	253	356
3	Translational kinetic energy	kJ	22	1.958	184	260
4	Rotational kinetic energy	kJ	9	646	69	99
5	Translational velocity	m/s	3	25	6	4
6	Rotational velocity	i/s	3	27	7	5
7	Momentum	t m/s	17	158	41	26
8	Angular momentum	t m²/s	6	48	13	8
9	Angle against barrier	°	-123	-72	-87	17

Table 2: Numerical results of ROCKFALL 6.0

To catch 100 % of the rocks a barrier height of 5.77 m would have been required, but table 4 indicates that 99.7 % of the rocks had a bounce height of less than 4 m at the proposed barrier location. The maximum kinetic energy was 2,512 kJ, but 99.6 % of the rocks had a kinetic energy of less than 1,500 kJ. Modern rockfall barriers are able to absorb kinetic energies of more than 2,500 kJ.

Compared to the rockfall frequency it was considered to be uneconomic to chose a height of more than 4 meter and to go beyond 1,500 kJ. By the way about 90 % of the rocks had energies less than 1,000 kJ. The annual events would require no excessive maintenance therefore.

On the base of the simulation JR decided to built a 4 m high, 150 m long RX 150 fence at the location of the most upper fence. The fence was delivered by Swiss enterprise Fatzer AG, Romanshorn, and installed by Japanese contractor Toa Grout Kogyo Co., Ltd., Tokyo, in 1998. It was the first modern ring net fence in Japan. Meanwhile more than 5.000 m of these fences have been installed.

Acknowledgements

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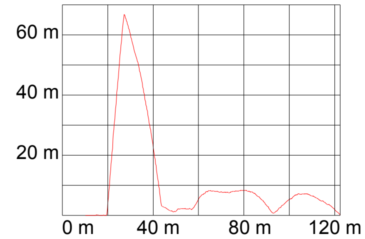
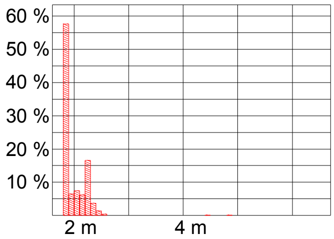
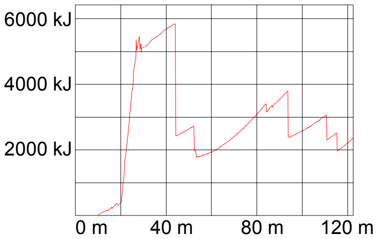


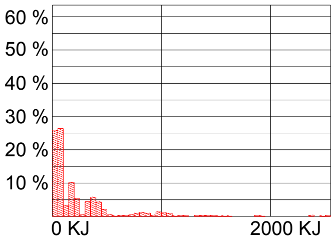
Envelope curve: bounce height



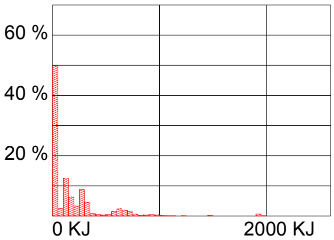
Bounce height distribution



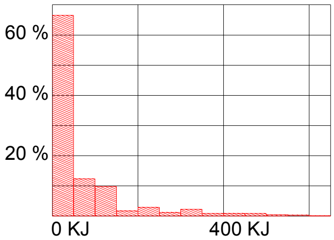
Envelope curve: total kinetic energy



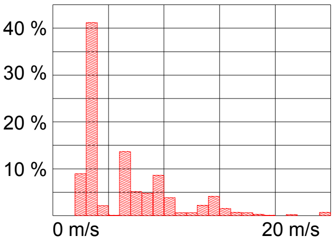
Total kinetic energy distribution



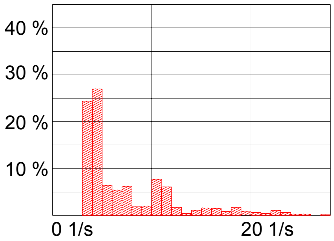
Translational kinetic energy



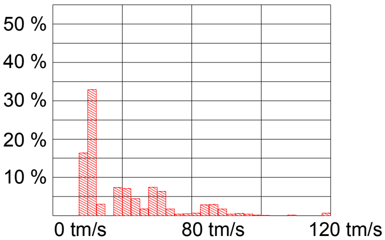
Rotational kinetic energy



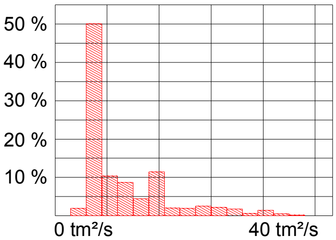
Translational velocity



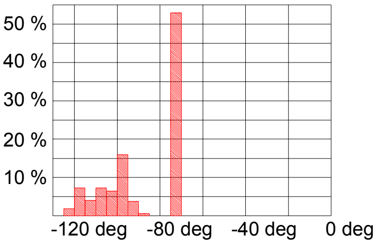
Rotational velocity



Momentum



Angular momentum



Angle against barrier

Table 3: Graphical presentation of ROCKFALL 6.0 results

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(2) SPANG, R. M. (1988): Empirical and mathematical approaches to rockfall protection and their practical applications. – 5th Int. Symp. Landslides, Lausanne.

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