



Mitigating of Rockfall Risks

(Case Study: Klösch Rockfall, Austria)

Alexander Preh
University of Vienna
Geotechnics Engineering
Vienna, Austria
preh@tu.ac.au

Ari Sandhyavitri
University of Riau
Engineering Faculty
Pekanbaru, Indonesia
arisandhyavitri@gmail.com

Abstract—Rockfall cases are a natural and dynamic geologic process, commonly occur within mountainous areas near by the cliffs undercut by human for developing building or highway. This paper simulated rockfall process within manmade slope in the quarry at the Kloch, Austria. This paper revealed 7 (seven) slope surface parameters for this slope, including; dynamic and static friction angles (35°), normal and tangential damping (0.2 and 0.95 consecutively), rolling resistance (0.2 to 0.3), amplitude of roughness (0), and frequency of roughness (1). These results were then treated as an input data in the simulation of the designated rockfall. Based on the simulation results, it was identified that the Kloch slope height was 15 m, the rockfall would yield the kinetic energy of 240 kJ, and 0.5 m of bouncing height. Hence, in order to protect toe area from the rockfall risks, it is recommended to construct a minimum 1 m height of retaining wall with a capacity to restrain the rockfall kinetic energy up to 500 kJ as an appropriate barrier for this case.

Keywords—rockfall, mitigation, simulation, energy kinetic, bounce height, barriers.

INTRODUCTION

Inevitably, rockfall cases occur mainly in the mountainous areas of man made cut off slope ones. Rockfall causes damage to buildings, housing and settlements, road infrastructures, and threatening of human life (Raymund M Spang, 2001a, b, Ari Sandhyavitri, et al, 2010, Kristen L. et al, 2003).

In order to mitigate the magnitude of the rockfall risks, it is necessary to carryout simulation of the rockfall trajectory along the slope profile and calculating of the rockfall's kinetic energy as well as its bouncing height after hitting the ground (Kristen L. et al, 2003, Lawrence A. Pierson, C.E.G. Robert Van Vickle, R.P.G, 1993). This paper utilizes the experimental rockfall data in Kloch, Austria. These data are provided by the University of Vienna, Centre for Geomechanic, Austria.

A 2-D computer program Rockfall 6.1 was applied for simulating this rockfall data. This Rockfall application package has been widely applied in several countries such as in Austria, Slovenia, Germany, and Japan (Spang, 2003, Dorn L., 2003, Guzzetti F., et al, 2002, Hoek, E. 2005, Iau-Teh Wang and Chin-Yu Lee, 2010, and Matjaž Mikoš, Urška Petje, and Mihael Ribičič, 2006).

II. SLOP CHARACTERISTICS

From the site investigation data, it was identified that the height of Kloch Slope was 15 m, with an average degree of 68° (Figure 1). The geological of the slope rock was andesyt rock with the average mass of 2.9 tonnes/m³.

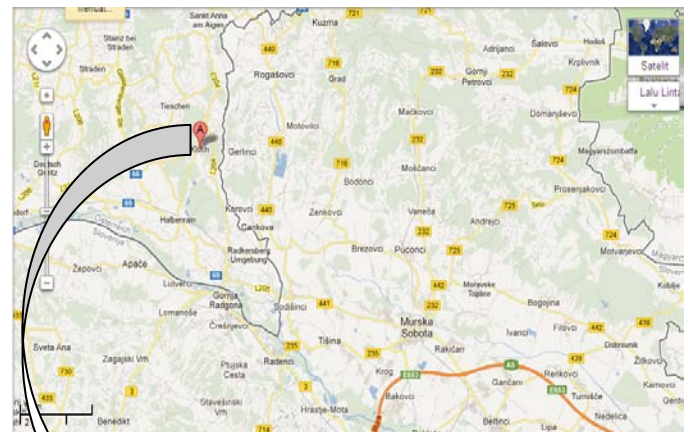


Figure 3 Slope of Kloch Profile (Souce: Documentation of the University of Vienna, Centre for Geomechanic, 2011)

III. RISK ASESMENT



An initial stage to analyze of the rockfall risks is by identification of the slope surface qualities.

The slope surface quality was determined by trial and error method. This method compares between the actual distance (of the rock blocks rolling to a stop on flatter ground), and the results from the rockfall simulation.

After extensive repetition on simulating the slope surface qualities from the Kloch profile using trial and error, it was then identified deviation between field data and the simulation. A relatively small deviation of the results, then it was considered the simulated data results can be acceptable (Table 1 and 2).

TABLE 1. The slope surface qualities from the Kloch

Surface Qualities/Parameters	Max. Value	Min. Value
Dynamic Friction angle in case of sleeding (Rg)	30°	30°
Static Friction angle in case of static contact (Rh)	35°	35°
Normal damping velocity during collosion (Dn)	0.2	0.2
Tangential damping paralell to the slope surface (Dt)	0.95	0.92
Rolling resistance; energy loss of the rolling rock (Rw)	0.3	0.25
Rough Amplitude, vertical distance (oa)	0.05	0
Rough Frequency, horizontal distance (Of)	1	0

Source: Data Analyze, 2014.

The surface qualities of the designated slope were identified as follow; (i) dynamic and static frictions angel were 30° and 35° consecutively, (ii) normal damping and parallel one 0.2 and 0.92, and (iii) rolling resistance was in between 0.25 and 0.3. The slope rough amplitude and frequency are relatively low as field data of the slope surface were obtained very detail.

TABLE 2. Comparing the distance between field data and simulation results

No.	Distance based on simulation results (m)				Distance based on the field data (m)	Deviation standard
	1	2	3	average		
1	9.02	8.95	9.02	9.00	9	0.0%
2	7.59	6.93	6.71	7.08	7	0.2%
3	4.62	3.37	5.34	4.44	4.5	0.3%
4	7.39	7.75	8.31	7.82	7.6	0.4%
5	8.22	6.76	8.51	6.83	6.7	0.3%
6	2.47	3.18	1.95	2.53	2	13.3%
7	9.58	10.01	9.76	9.78	10.4	0.6%
8	2.4	2.47	2.76	2.54	2.5	0.7%
9	11.96	12.03	12.21	12.07	12.2	0.1%
Average of Deviation standard						1.8%

Hence, base on Table 2, it was summarized that the rock blocks distance between field data investigation and rockfall

simulation package was considered acceptable (with an average of the deviation standard was 1.8%).

Second stage is understanding the rockfall trajectory. Based on the simulation (using 100 rockfall blocks), with the radius of stone size of 0.5 m, and the estimated block's weight of 2.9 tones / m³, the profile of passing rock blocks for this slope can be seen in Figure 2.

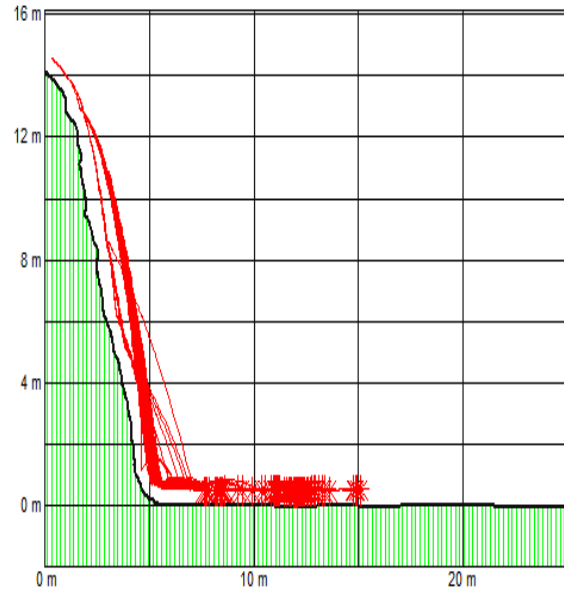


Figure 2. Profile of passing rockfalls (Source: Data Analyses, 2013)

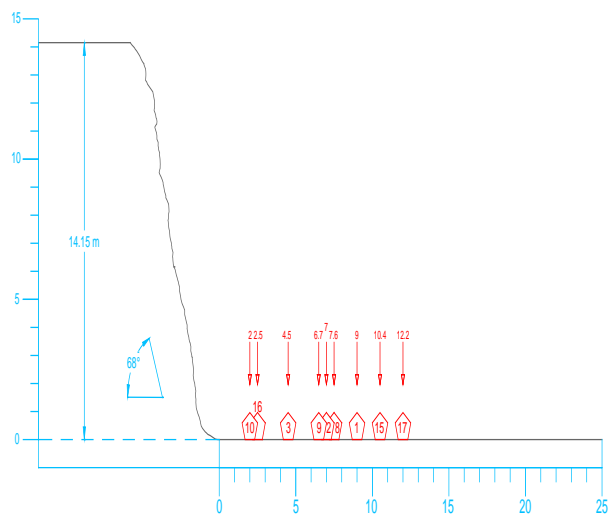


Figure 3. Profile passing rocks (Based on the real experimental data of rockfalls, 2011). Source: Data Analyses, 2013

The Figure 3 above projected the location of the rockfall blocks stationary on the flat ground surface after they were losing their energy. It was identified that the distance of rockfall stationary after hitting the ground level was calculated between 2 m to 10 m from the slope toes. The simulated results confirmed the field data.



IV. RISK MITIGATION

Hence, it is recommended that, in order to reduce risks of rockfall blocks destroy road pavement, the width of road shoulder should be > 10 meters from the slopes toes.

Since there is a limited space of the road shoulder (<10 m) from the slope toe, it necessary to construct rockfall barrier to restrain the rockfall energy hitting the road pavement or other related building slope toe.

The location of the barrier is designated to be close enough to the slope toe. It is also highlighted that the constructed barriers should be able to restrain kinetic energy of the rockfalls striking the barriers. The height of the constructed barrier should also be greater than the bouncing height of the rockfall after hitting the ground level.

Based on the simulations for the 100 block of rockfalls (with a diameter of 0.5 m), it was revealed that the envelope of the total kinetic energies were > 200 kJ and rockfall bouncing height was up to 0,5 m. This can be seen in Figure 5.

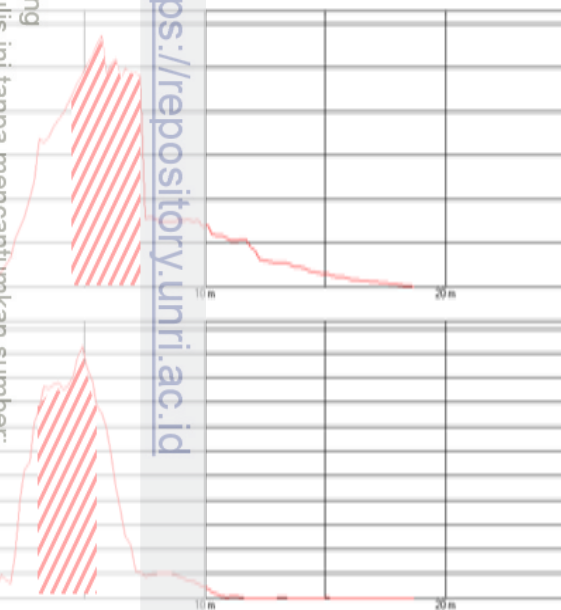


Figure 5. Distribution of kinetic energy and rockfall bouncing height,

From the figure 5, it can be seen that the region with the largest kinetic energy occurs at a distance of 4.5 to 7 m from the slope toe. The bouncing height of the rockfall was calculated to be 3.5 to 4.5 m height.

Based on the simulation results using 100 rockfalls, it was also identified that 98% probability of the number of the rockfall blocks will be stop at the distance of 7 m from the slope toes, (Figures 3 and 4). There is also 0% probability the number of rockfalls may roll-on or slide at the distance of 17.5 m from the form the X-abscess of the slope (Figure 4).

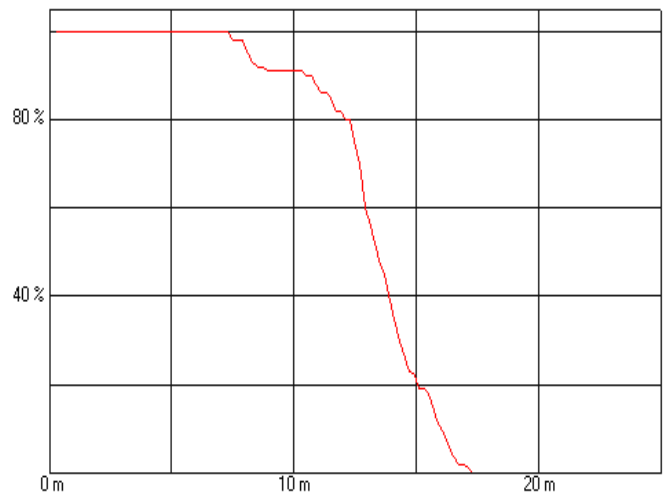


Figure 4. The probability of rockfall numbers (in %) versus the distance of the rockfall to stationary (m).

The number of rockfall blocks hitting the ground tend to decline at a distance of 7 m up to 17,5 from the slope (Figure 4). The number of rockfall blocks hit on the ground is correspondence to the rockfall risk zone.

This paper presents 3 different risk zones for rockfall; (i) high risk zone, (ii) medium risk, and (iii) low risk (Figure 5). In act, this rockfall risk zone also applied in many cases in the Europe (Papathanassiou G, Valkaniotis S, and Chatzipetros A. 2005).

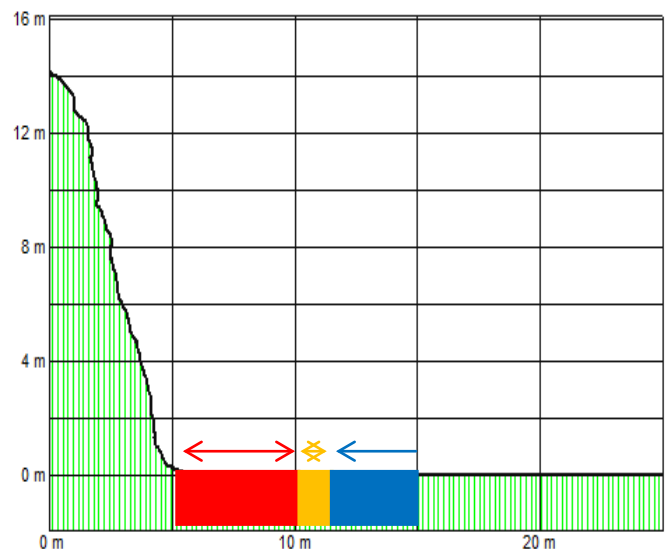


Figure 5. Rockfall risk zones.

Figure 5 describes, there is 80% of probability (of the number of rockfall) to stop/stationary within the red zone risk. There is 20% of probability (of the number of rockfall) may reach the yellow zone. The remaining blue zone is considered safe zone (almost 0% probability of the rock may reach this area). Hence, in this case, it was designed to construct a



barrier located at a distance of 2 m from the slope toe or 7 m from the X abscess of the slope (Figure 6).

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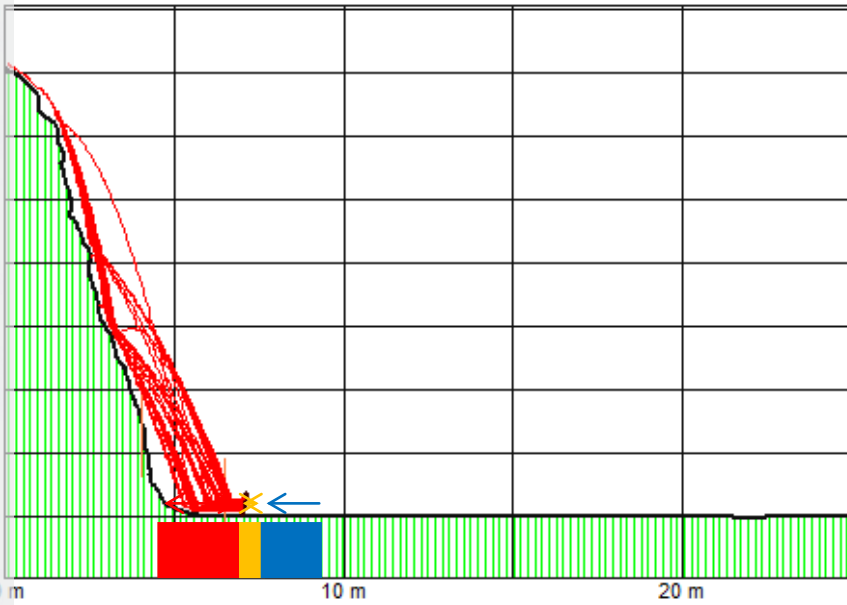


Figure 6. Simulation of 100 rockfalls hitting designed barriers
Source: Data Analyses, 2014

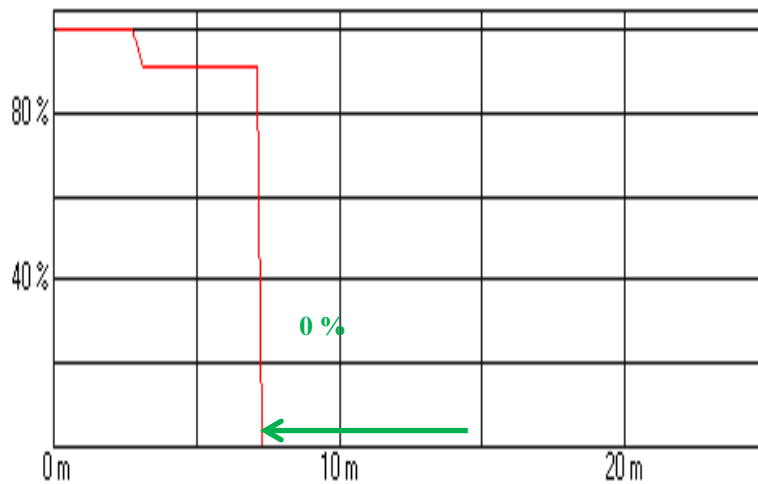


Figure 7. Probability number of rockfall vs distance to stationary (Data Analyses, 2014)

After 100x rockfall block simulation, it was identified that approximately 99,9% of rockfall blocks stop at the barriers (Figures 6 and 7).

Hence, barriers types and heights then calculated using Rockfall application. Based on cumulative histogram for kinetic energy of rockfall hitting the barriers was as follow (Figure 8),



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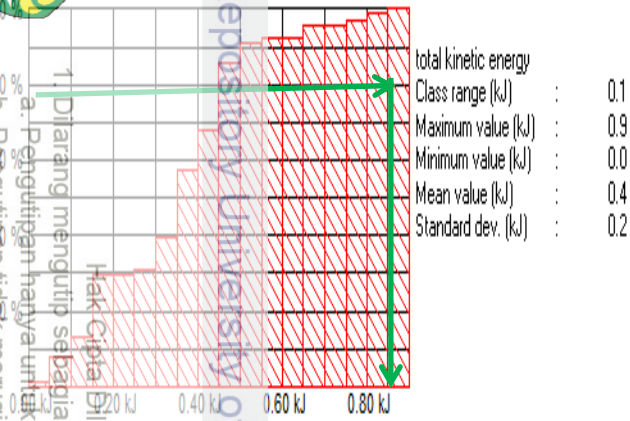


Figure 9, Type of retaining wall for rockfall barrier



Figure 9, Type of retaining wall for rockfall barrier

TABLE 4. KINETIC ENERGY OF 100 DAN 1000 ROCKFALL BLOCKS (RADIUS = 0,5 M)

Simulation	100 rocks (0,5 m size)
Kinetic energy (maximum)	244.9 kJ
Kinetic energy (minimum)	0.5 kJ
Kinetic energy (average)	53.8 kJ
Bouncng height (maximum)	0.44 m
Bouncng height (minimum)	0 M
Bouncng height (average)	0.1 m
Kinetic energy 80%	50 kJ
Bouncng height 80%	0.25 m

(Source: Data Analyzes, 2014)

It is summarized that the kinetic energy maximum was approximately 240 kJ, and bouncing height maximum was 0.5

m. In the state of the art analyses, it is recommended to design type of the rockfall barriers was retaining wall. Theoretically, type of retaining wall is able to restrain the kinetic energy up to 500 kJ (>244.9 kJ). The height of the retaining wall was designed to become 1 m height.

CONCLUSION

Based on the rockfall analyses results, it was revealed that, for the condition of 14 m slope height, an the average degree of 68° , the rockfall kinetic (energy when hitting) a barrier (located at of 2 m from the slope toe) was approximately 240 kJ, and the bouncing height maximum was 0.5 m from the ground level. Hence, for the rockfall mitigation scheme it is recommended to construct a retaining wall to control the rockfall risk (h minimum = 1 m).

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