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Rockfall analysis using simulation techniques - A practical application to the Mt. Namsan Gyoungju in Korea

Jong Yoon Lee, Hyeong Dong Park
Seoul National University, Seoul, Korea

Abstract: During the last few decades, the frequency and distribution of rockfalls have been increased in Korea due the development of rock slope in mountain areas. Although the scale of falling block of rockfall was small, there were some casualties of lives and loss of properties. In order to reduce damage from rockfall, analysis on rock slope indanger of rockfall should be carried out. Thus, the simulation softwares for rockfall behavior analysis have been introduced. In this study, geotechnical investigation and input data for rockfall simulation are described with the comparison among four commercially available rockfall simulation softwares. Finally, rockfall simulation works are described by exmining a case of inaccessible rock-slope of potential rockfall in Korea.

1. Introduction

Recently, the 90% of the slopes aside new corridors have been constructed in mountainous areas which are primarily consisted of rock. Rockfall occupied up to the 43% of the landslide in Korea (Baek et al., 2001). Rockfalls pose serious hazards to lives, properties and highways. Above all, the most serious problem of rockfall is on the rise non-operation expenses. Over the past few decades, a considerable number of studies have been conducted on the analysis of hazardous rockfall throughout the world. They can be classified two categories according to the approach method; 1) Historical, empirical and physical modelling methods, 2) Simulation techniques using computer.

In Korea, it is necessary to study reliable prediction and analysis of rockfalls for hazard assessment, countermeasure design and remedial activities. The first purpose of this study is to understand how to predict and analyse rock slope with rockfall using simulation techniques. The second is to introduce how to make practical application of rockfall simulation.

This study presents a practical application to the rock slopes of Mt. Namsan in Gyoungju and its historical bas-relief of Buddha to show the considerable potencial hazards of rockfall in Korea.

2. Rockfall Characteristics and Triggering Events

Characteristics of rockfall

Rockfalls have some characterization about geotechnical engineering and mechanics.

1.Although rockfall has limits to its volume, it can cause serious problem by its high energy and mobility.

2.Rockfall is extremely difficult to be reconstructed, because there were no direct witnesses, the target area is usually inaccessible and the time elapsed after the event.

3.The accurate prediction of rockfalls is practically impossible. Because slope geometry is highly variable, the location where the rock begins is often unknown, the slope material can be variable or the relevant material properties not well known

4.Rockfall dynamics is a complex function of the starting point and the geometry and mechanical properties of both the block and the slope.

Triggering events in Korea

In Korea, most rockfalls are associated with triggering events which consist of some climatic and biological changes, such as rainfall infiltration caused to increase pore pressure, freeze-thaw processes generated fatigue failure in winter and erosion of surrounding material during heavy and long rainfall, chemical degradation or weathering of the rock, root growth or leverage by roots moving in strong winds. However, some rockfalls occur without a direct correlation to an obvious triggering events. For example, these rockfalls are due to processes associated with gradual stress release and exfoliation of granitic rocks. These events cause a change in forces acting on a rock, and increase pore pressure. In the long run, rockfalls are genetated.

3. Comparison among Simulation Techniques

Brief review of conventional rockfall simulation methods

Analytical computer models can be roughly divided into two types. 'Lumped Mass Method' is based on two computational hypothesis. The one is a two dimensional definition of the incline in terms of straight line segments. The other is the reduction of the block to a point object with no account of air resistance. In this way the trajectory results as composed by a series of parabolic trace from the point of departure to the point of first impact and then again for each bounce a new parabola until the boulder comes to rest. The determination of these parabola, of the change in velocity, and energy is returned by relevant equations.

'CRSP Method (Colorado RockFall Simulation Program)' was developed by Pfeiffer & Bowen (1989). It enables the modelling of falling blocks having spherical, cylindrical or diskform. CRSP describes the behaviour of the blocks by applying the equations of parabolic trajectory of bodies in free fall and the principle of conservation of total energy. The roughness of the slope and the dimensions of the blocks are used as additional parameters to model the impact event. Specifically, CRSP assumes that the angle formed between the direction of the block and the slope profile, be varied in accordance with statistics to be specified for the particular case. Thus the model considers combinations of movement in free fall, bounce, roll, and slide that can vary in relation to the size of the blocks and the roughness of the slope.

Advantages of rockfall simulation

Until recently, rockfall simulation softwares were developed for modelling rockfall and providing statistical analysis of probable of rockfall behavior at any given site. This analysis can be used as tool to study the behavior of rockfall, determine the need for rockfall mitigation, and aid in the design of rockfall mitigation.

Compared to the historical and the empirical approach, rockfall simulation has considerable advantages (Spang, 1988). 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 and the size of rocks is exaggerated. In contrast Rockfall simulation is always applicable, quick and reproducible. It can be combined with the historical approach and can evaluate rockfall tests on a sound scientific base. The extensive statistical output can be used for modern probabilistic approaches to safety.

Comparison among Four Commercial Rockfall Simulation Softwares

There are four commecial computer softwares for rockfall simulation. Respectively, CRSP, Rocfall, Georock and Rockfall were developed by 'Corolado Department of Transportation', 'Rocscience', 'Geostru' and 'Geotechnical and Civil Engineering Consultants LTD'. The softwares of comparison and analysis are shown in Table 1. And they can be used for the follwing applications:

1.Evaluation of risk assessment of slope at risk of rockfall.
2.Examination of exisiting rockfall barriers.
3.Assistance in determining remedial measures
4.Optimization of the position and dimension of protection structuress as for height and energy.

Table 1. Parameters determining behavior of rockfall in four simulation softwares.

Factor	Parameter	CRSP	Rocfall	Georock	Rockfall	Dim
Steering Parameters	Terminal Limit Velocity	O	O	O	O	m/s
	Number of rock-block	32,767	10,000	1,000	10,000	-
	Angle of variation(Statistic,Deterministic)	S	S, D	S, D	S	-
	Initial Motion(Free Fall or Roll/Slide)	X	O	X	O	-
	Method(L.M.M., CRSP)	CRSP	All	All	CRSP	-
Slope Geometry	Slope Length	O	O	O	O	m
	Surface Roughness – amplitude	O	O	O	O	m
	Surface Roughness – frequency	X	X	X	O	m
	Stochastic Model	X	O	X	X	-
Slope Material Properties	Static Friction	X	O	X	O	deg
	Dynamic Friction	X	X	X	O	deg
	Rolling Resistance	X	X	X	O	deg
	Coefficient of Normal Restitution	O	O+	O	O	-
	Coefficient of Tangential Restitution	O	O	O	O	-
	Stochastic Model	X	O	O	O	
Rock Geometry	Rock Shape(Sphere,Cylinder,Disk)	All	S	All	S & C	-
	Rock Size(Variation)	O	X	O	O(V)	m
	Rock Length	O	X	O	O	m
Rock Material Properties	Rock Mass / Density	D	M	D	D	-
	Modulus of Elasticity	X	X	O	X	kg/m²
	Initial horizontal velocity	O	O	O	O	m/s
	Initial vertical velocity	O	O	O	O	m/s
	Initial angular velocity	X	O	X	O	rad/s
	Stochastic Model	X	O	X	O	-
Barrier	Size	X	O	O	O	m
	Inclination		O	O	O	deg
	Depth(under ground)		X	O	X	m
	Plastic / Inplastic		O	X	X	-

4. A Practical Application to the Mt. Namsan in Gyoungju

The main purpose of this chapter is to analyze a considerable potential rockfall around the historical bas-relief of Buddha, Mt. Namsan Gyoungju in Korea. The Mt. Namsan is located at souththern boundry of the city of Gyoungju. This statue (Fig. 1) is engraved on the granite rock block separated by sheeting joints and there are severely fractured zone around the statue. Above all, the slope is inaccessible caused by religious motive and cultural property.

Geology in the target area

As to geology, the area belongs to the granite mass which is widely ditributed in the western part of Gampo quadrangle (1:50,000) and extended to the eastern part of Moryang quadrangle. The mass is elongated in the direction of N20W in Gampo quadrangle. The lower part of the slopes is covered by Quaternary deposits, namely cemented slope deposits, and recent screee slope and alluvial deposits (Lee *et al.*, 1999).

The rock slope consists of vertical rock-walls about 40m high with a slope angle of 70 to 90 and is seperated by steep slopes covered with vegetation, talus deposits or outcrop. This morphology is due to subvertical joint systems formed during the cooling of the magmatic rocks. The slope is consisted of South gently dipping granite. At the bottom area of the walls, a little talus deposits caused by rockfall, with the size between $0.05m^3$ and $6m^3$, can be found.

Field survey allowed to collect detailed calibration data for numerical modelling (starting points or sections, geometry of single blocks fallen on the slopes) and to assess the geomechanical features of the rock mass. One of the significant parameters affecting the size of rockfall debris is joint spacing, because a rock block enclosed by intercrossing joints tends to be detached from the rockwall. A window survey was employed to determine joint spacing.

Interpretation of field survey and its analysis

The fracturing was caused by cooling of the magmatic rocks and weathering activity. The graphical presentation shows one joint set on the Schmidt net (Fig. 2) :

Set K1, 186/70, dipping to South and rarely to North; number of data: n=8; slope-parallel joint – this joint is parallel to the slope.

Discontinuity spacing ranges between centimeters and decimeters. The joint surfaces are mostly smooth and undulating. The mean joint roughness coefficient(JRC) yield 7.6 (Lee *at al.*, 2002). At the site, fracturing and weathering cause unstable plates of 0.8 × 0.5 × 0.9 m size.

As a result of stereonet analysis (Fig. 2), the slope expects plane and toppling failure.

Fig. 1. Whole view of the study site.

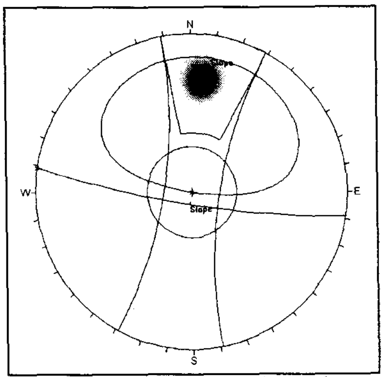

Fig. 2. Plot of the analysis on plane and topping failure.

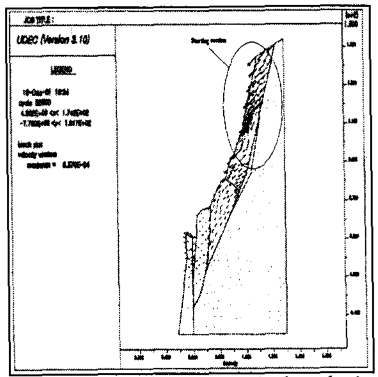

Fig. 3. Result from numerical analysis using UDEC.

Result of a practical application using simulation technique

As rockfall simulation is executed, the most difficulties work is selecting rockfall path and starting points of rock block. In this study, in order to decide rockfall path, UDEC was utilized; to determine starting points, DIPS was used. According to the interpretation of results, the slope is danger due to slip of rock block on the upper slope. Because the section was shown as more larger displacement than other sections (Fig. 3). So the critical starting point of rockfall can be selected.. Also, rockfall path can be determined. As shown Fig.1, the slope is nearly parallel to the joint. And the direction of plane and toppling failure is nearly coincidence with the dipping of the slope. As a result of this relation, rockfall path was selected by the slope N-S striking. Fig. 3 is presented by the steps of prediction and analysis of rockfall for inaccessible rock slope in this study.

As a result of rockfall simulation using 'Rocfall'; when it will be assumed to generate rockfall, the impat energy is up to 4kJ at the head of the statue and from 6kJ to 18kJ at around the seat of religious service.

5. Conclusions

About inaccessible rock slope which the reason is religious motive and cultural property, using simulation techniques which offer easy and realiable results of the rockfall analysis, the potential hazard for rockfall was analized quantitatively.

1.The displacement for the head of the statue is generated in the numerical analysis using UDEC, besides, when rockfall will be assumed to happen, the value of impact energy at the position is up to 4kJ. Because the failure is expected, in order to pretect the statue, countermeasure is required.

2.When rockfall occurs, the impact energy of the altar location is 6~18kJ. This value is alike the energy which occers when 0.5 ton vehicle collides something at speed per hour 30km. The countermeasure is demanded consequently.

3.When using rockfall simulation softwares, the most difficult thing is to select 'rockfall path' and 'starting point'. In order to find 'starting point', the segment where it is visible a relativy big displacement in numerical analysis is designated 'starting point'. Selecting the Rockfall-Path used a Stereonet analysis.

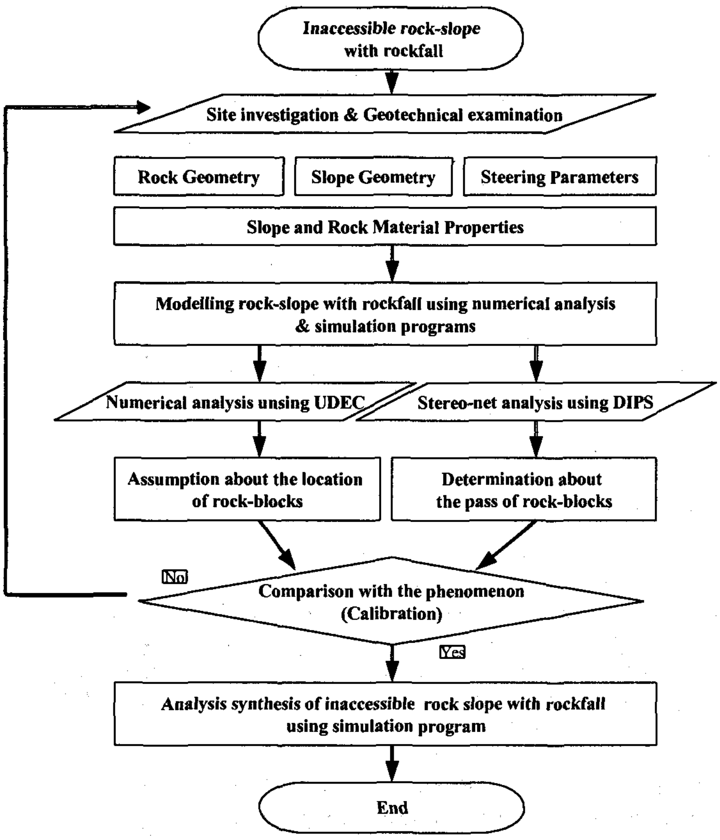

Fig. 4. Flow chart showing the steps of prediction and analysis of rockfall for inaccessible rock-slope in this study.

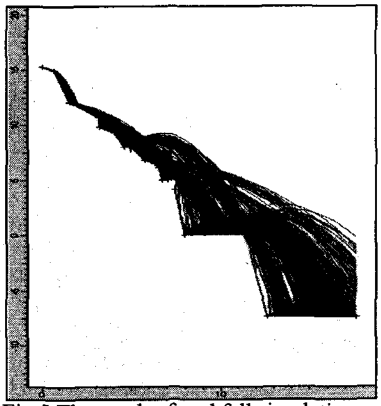

Fig.5 The result of rockfall simulation about the trajectory.

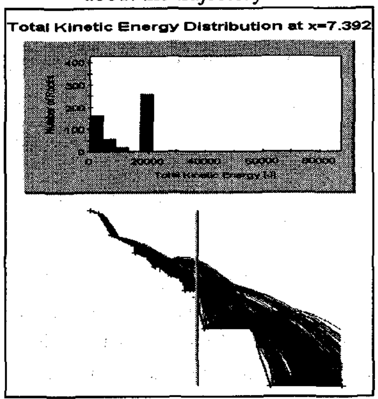

Fig. 6. The result of rockfall simulation at the head of the statue.

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References

Spang, R.M. (1988) Empiricqal and mathematical approaches to rockfall protection and their practical applications. %th Int. Symp. Landslides, Lausanne. Pp. 121-145.

Pfeiffer, T, Bowen, T. (1989) Computer simulation of rock falls. Bull. Assoc. Eng Geol. Vol. 26 No. 1, pp. 135-146.

Lee, J.D.and Hwang, B.H. (1999) Petrology of the granitoids in the Namsan-Tohamsan area around Gyeongju, Korea, Jour. Korea Earth Science Society, Vol. 20. No. 1, pp. 80-95.

Jones, C.L., Higgins, J.D. & Andrew, R.D. (2000) Colorado Rock fall Simulation Program Version 4.0, Manual. pp. 3-47.

Baek, Y., Koo, H.B., Park, S.W. & Bae, G.J. (2001) Study on Failure and Movement Pattern along road slopes in Korea. , Proc. of 2003 conference of the Korean Society of Civil Engineers, pp. 1-4.

Lee, J.Y. and Park, H.D. (2002) Application of Statistical Methods to a Variety of Slope Stability, Thesis for the Master degree of Seoul National University, pp. 61-70.