Fragmentation and Deposition of Rock Mass with Joint Strength during Rockfall

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EGU General Assembly 2011
Vol. 13, EGU2011-5156
Board Number : XY457

行政院國家科學委員會 National Science Council
96-2628-E-002-180-MY3
99-2218-E-002-033-
NTU RM&EG

Abstract

The fragmentation of rock mass with joint strength and its influence on the deposition during rockfall is important for rockfall hazard evaluation. Different degree of damage within rock sheds had been observed in two cases located at the Central Cross-Island Highway of Taiwan.

Small-scale laboratory rockfall experiments were performed to investigate the rockfall process of rock mass with joint strength. Then distinct element method (PFC3D) was used to simulate the fragmentation and deposition process. In addition to the details of the fragmentation and interaction of blocks, energy transformation and dissipation can be discussed in the numerical simulation. When the numerical simulation tool was validated, it was applied to the in-situ Tzau-An Cliff rockfall case with minor damage of the shed due to fragmentation before the impact of rock blocks.

The laboratoric rockfall tests are revealed that the joint strength has a negative trend with the run-out distance. In addition, when increasing the volume of rockfall, the run-out distance after fragmentation and the volume of mass which near the toe will increase. The range of deposit differs depend on size of rock mass with different joint strength, and the run-out distance in the case of 45 degrees slope below the cliff that is farther than the one which impact directly on the ground level, and the mass breaks in more pieces.

Keywords: rockfall, rock mass with joint strength, fragmentation, rockfall test, distinct element method, PFC3D

1. Introduction

- Rockfall can either destroy or do little impact to two rock sheds (Fig. 1&2 v.s. 3&4 respectively).
- The impact force and energy should be transformed that depend on the level of fragmentation in rock.
- The upper slope of rock sheds are simplified to 45 and 90 degrees through field investigation.

Fig.1 Maling No.3 rock shed before 921 Chi-Chi earthquake. It was stable and maintained the security of transportation.

Fig. 2 Maling No.3 rock shed after 921 Chi-Chi earthquake. It was destroyed due to the impact of rockfall.

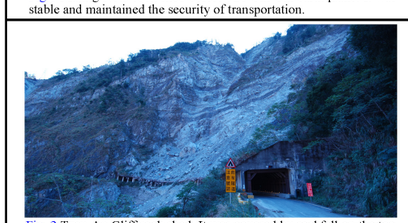

Fig. 3 Tzau-An Cliff rock shed. It was covered by rockfall on the top of the shed.

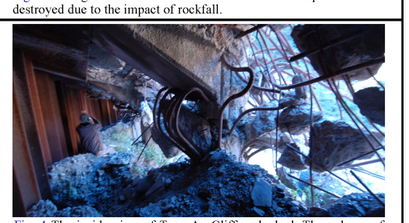

Fig. 4 The inside view of Tzau-An Cliff rock shed. The column of the shed was buckled but not collapsed.

2. Methodology

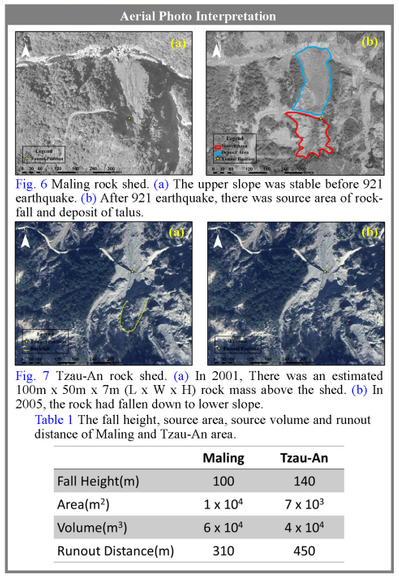

Fig. 6 Maling rock shed. (a) The upper slope was stable before 921 earthquake. (b) After 921 earthquake, there was source area of rockfall and deposit of talus.

Fig. 7 Tzau-An rock shed. (a) In 2001, There was an estimated 100m x 50m x 7m (L x W x H) rock mass above the shed. (b) In 2005, the rock had fallen down to lower slope.

Table 1 The fall height, source area, source volume and runout distance of Maling and Tzau-An area.

	Maling	Tzau-An
Fall Height(m)	100	140
Area(m^2)	1×10^4	7×10^3
Volume(m^3)	6×10^4	4×10^4
Runout Distance(m)	310	450

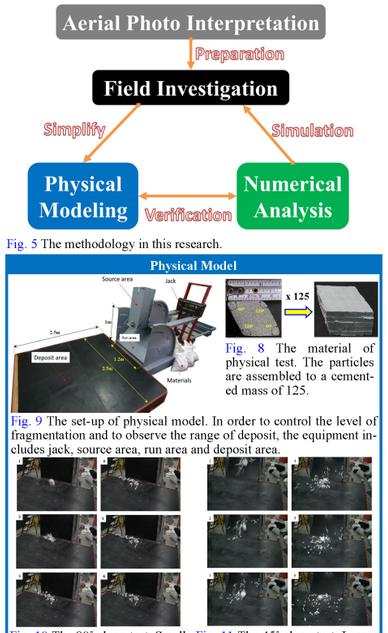

Fig. 5 The methodology in this research.

Fig. 8 The material of physical test. The particles are assembled to a cemented mass of 125.

Fig. 9 The set-up of physical model. In order to control the level of fragmentation and to observe the range of deposit, the equipment includes jack, source area, run area and deposit area.

Fig. 10 The 90˚ slope test. Smaller deposit area is observed.

Fig. 11 The 45˚ slope test. Larger deposit area is observed.

Numerical Analysis

Table 2 The total items of physical tests. All of it are simulated by numerical analysis to calibrate.

Test Name	Control Condition: Impact Rock Number	Control Condition: Drop Distance (cm)	Control Condition: Slope(˚)	Joint Strength (Pa)	
Rock with joint strength test	8	110	90& 45	Normal = 6 x 10^8 Shear = 7 x 10^8	Entire-broken (A)
	27			Normal = 1.75 x 10^8 Shear = 4.375 x 10^8	Partial-broken (B)
	64	110	90	Normal = 6 x 10^9 Shear = 7 x 10^9	Unbroken (C)
Rock without joint strength test	8	110	90& 45	-	
	27				

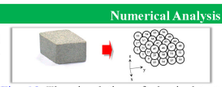

Fig. 12 The simulation of physical test material in PFC (ball).

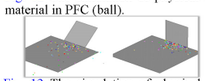

Fig. 13 The simulation of physical test slope in 45 and 90 degrees in PFC (wall).

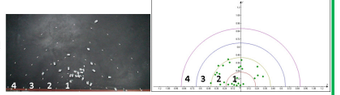

Fig. 14 The same slope condition (90 degrees) and particle numbers in physical test and numerical simulation. The numerical parameters are calibrated through mainly contrasting the deposit range, and the range is distinct in 4

3. Results

The change of energy dissipation is discussed including kinetic energy, friction energy and damping dissipated energy from joint strength high to low (Fig. 15~23) and the results are presented in table (Table 3). Finally in-situ situation is simulated to figure out the effect of rock with joint strength to rock shed (Fig. 24~26)(Table 4).

Table 3 The results of energy dissipation during rock mass falling .

A : Entire-broken B : Partial-broken C : Unbroken	Kinetic Energy (J)	Friction Energy (J)	Damping Dissipated Energy(J)
90˚ slope	C > A ≅ B	A > C >B	B > C >A
45˚ slope	A ≅ B	A > B	B > A
Compare 45˚&90˚ slope, in A condition	90˚ > 45˚ slope	45˚ > 90˚ slope	90˚ > 45˚ slope

The comparison of energy dissipation of 3 kinds of joint strength at 90˚ slope case

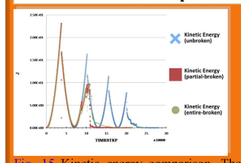

Fig. 15 Kinetic energy comparison. There are four peak kinetic energy in unbroken condition, because rock mass continues interacting with wall.

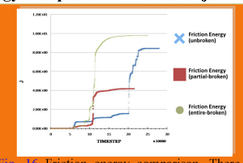

Fig. 16 Friction energy comparison. There is largest friction energy in entire-broken condition, and faster achieved peak value that means sliding of balls more than rotation.

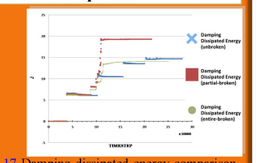

Fig. 17 Damping dissipated energy comparison. There is largest damping dissipated energy in partial-broken condition because impact is not only from ball to wall but also ball to ball.

The comparison of energy dissipation for rock entire or partial broken at 45 ˚ slope case

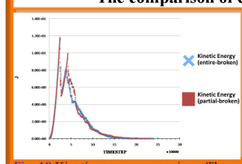

Fig. 18 Kinetic energy comparison. The result of kinetic energy dissipation is scarcely different, just like the 90˚ slope case (Fig. 19).

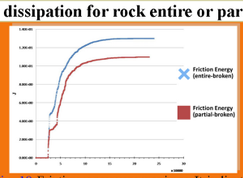

Fig. 19 Friction energy comparison. It indicates that friction is higher in entire-broken condition than partial broken because of larger contact area.

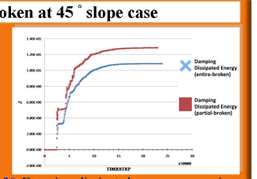

Fig. 20 Damping dissipated energy comparison. There is bigger block (mass) in partial-broken condition than entire-broken, so impact force (damping) is larger reasonably.

The comparison of energy dissipation between 90 ˚ & 45 ˚ slope cases in entire-broken condition

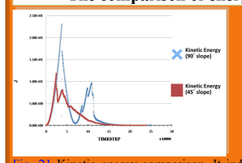

Fig. 21 Kinetic energy comparison. It indicates that kinetic energy is efficiently declined in 45˚ slope than in 90˚ slope.

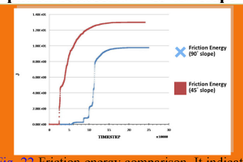

Fig. 22 Friction energy comparison. It indicates that the higher peak value is provided by 45˚ slope, it means rock mass has more opportunities to slide during movement.

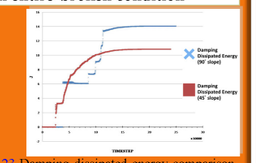

Fig. 23 Damping dissipated energy comparison. There is less sliding or rotation behavior in 90˚ slope, the energy dissipation is mainly due to impact (damping).

Simulation of in-situ cases

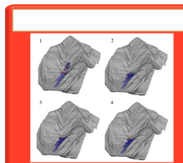

Fig. 24 The simulation of low joint strength. The rock mass instantly breaks when it falls.

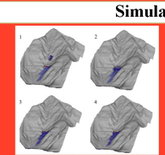

Fig. 25 The simulation of medium joint strength. The rock mass breaks during falling .

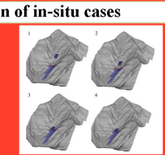

Fig. 26 The simulation of high joint strength, rock mass doesn't break until stop.

Table 4 The relationship between joint strength and impact force on rock shed. There is highest impact force on rock shed in unbroken condition.

	Impact force on rock shed(N)	Ratio
Entire-broken	2.88×10^7	1
Partial-broken	3.61×10^7	1.25
Unbroken	2.32×10^8	8.1

4. Conclusion

The behavior of rockfall motion is affected by the joint strength of rockfall, and the energy dissipation among low, medium and high joint strength (entire-broken, partial-broken and unbroken) is totally distinct through physical modeling and numerical analysis. The reason of rock shed of Tzau-An Cliff buckled but not collapsed after a giant rockfall striking is estimated that the rockfall was fragmentary and energy dissipated before it struck on the shed.