Catastrophic Landslide of Hsiaolin Village Kinetic Process and Deposit through Geomorphologic Analysis and Numerical Simulation

Chia-Ming Lo[1] Ming-Lang Lin[2] Chao-Lung Tang[3]
Jyr-Ching Hu[4] Jia-Jyun Dong[5] Chyi-Tyi Lee[6]

[1] Research Engineer, Geotechnical Engineering Research Center, Sinotech Engineering Consultants, INC.

[2] Professor, Department of Civil Engineering, National Taiwan University

[3] PH.D., Department of Geosciences, National Taiwan University

[4] Associate Professor, Department of Geosciences, National Taiwan University

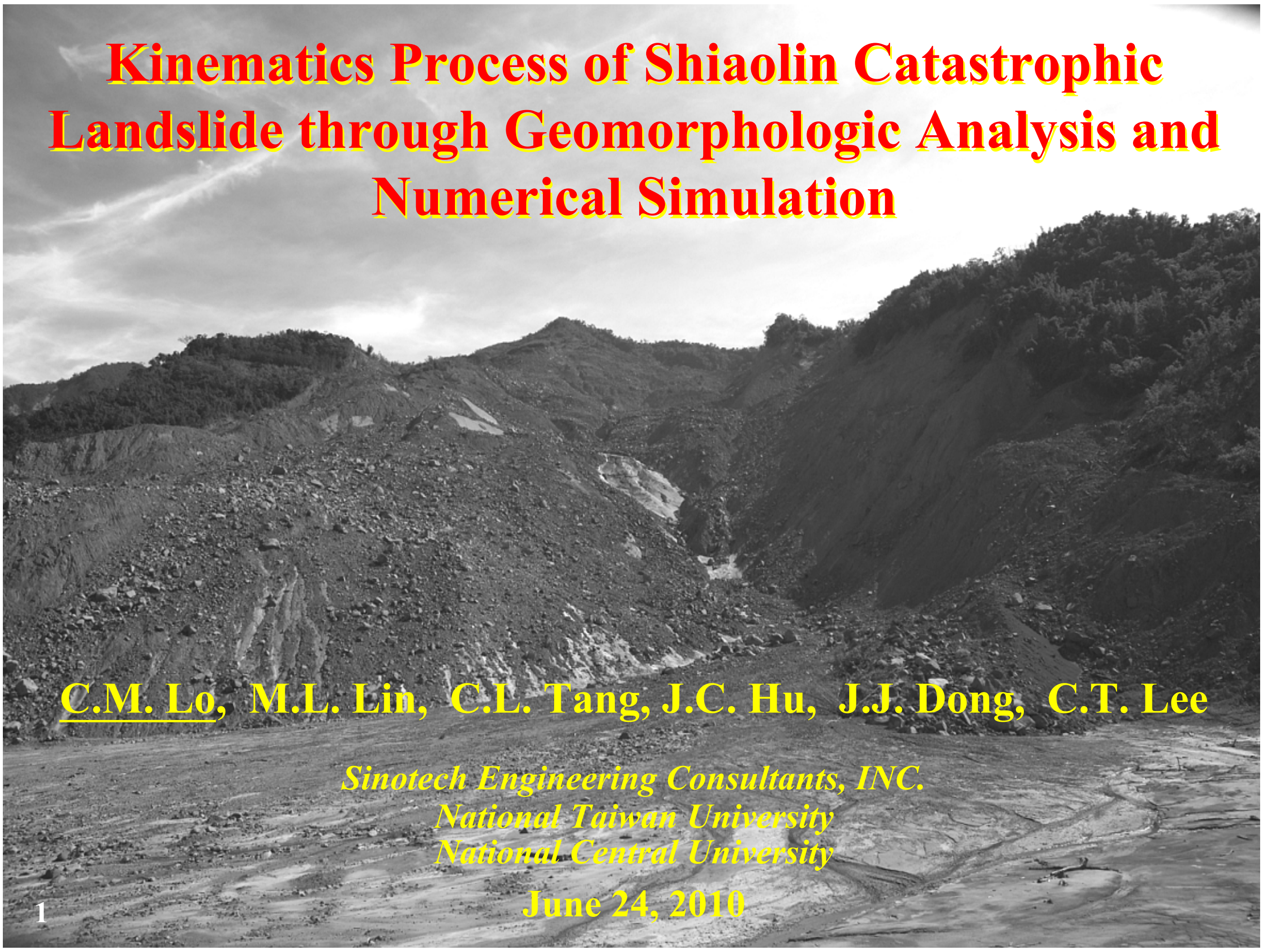
[5] Associate Professor, Graduate Institute of Applied Geology, National Central University

[6] Professor, Graduate Institute of Applied Geology, National Central University

Abstract

On August 2009, Typhoon Morakot with torrential rainfall brought a catastrophic landslide which buried about 5 hundred people and village in Hsiaolin village, Jiasian Township, Kaohsiung County. Therefore, many studies investigated and estimated the landslide mechanism of Hsiaolin village. However, there were few research evidences to support a causal relationship between kinetic process and the hazard zonation. This research aims at the estimation of catastrophic landslide kinetic process and deposit in Hsiaolin village. Based on geomorphologic analysis and field investigation, the source area (Xiandu Mountain) of slide locates at a stream head was covered by very thick colluvium of different ages. Then, the source area is too height above the village and deposition area, which caused high dynamic energy and enlarged the impact of the landslide. Numerical modelling of Hsiaolin village is carried out using a 3D discrete element program, PFC3D (Itasca, 1999). The landslide from debris slide converted to debris avalanche during the kinetic process. When the friction coefficient of each particle is equal 0.05, the predicated maximum velocity is about 80m/sec and the debris could reach to the other side of the Chishan River. Consequently was resulted the dammed lake and buried most of Hsiaolin village.

Keywords: *Catastrophic landslide, Hsiaolin village, geomorphologic analysis, Numerical modelling*



Kinematics Process of Shiaolin Catastrophic Landslide through Geomorphologic Analysis and Numerical Simulation

C.M. Lo, M.L. Lin, C.L. Tang, J.C. Hu, J.J. Dong, C.T. Lee

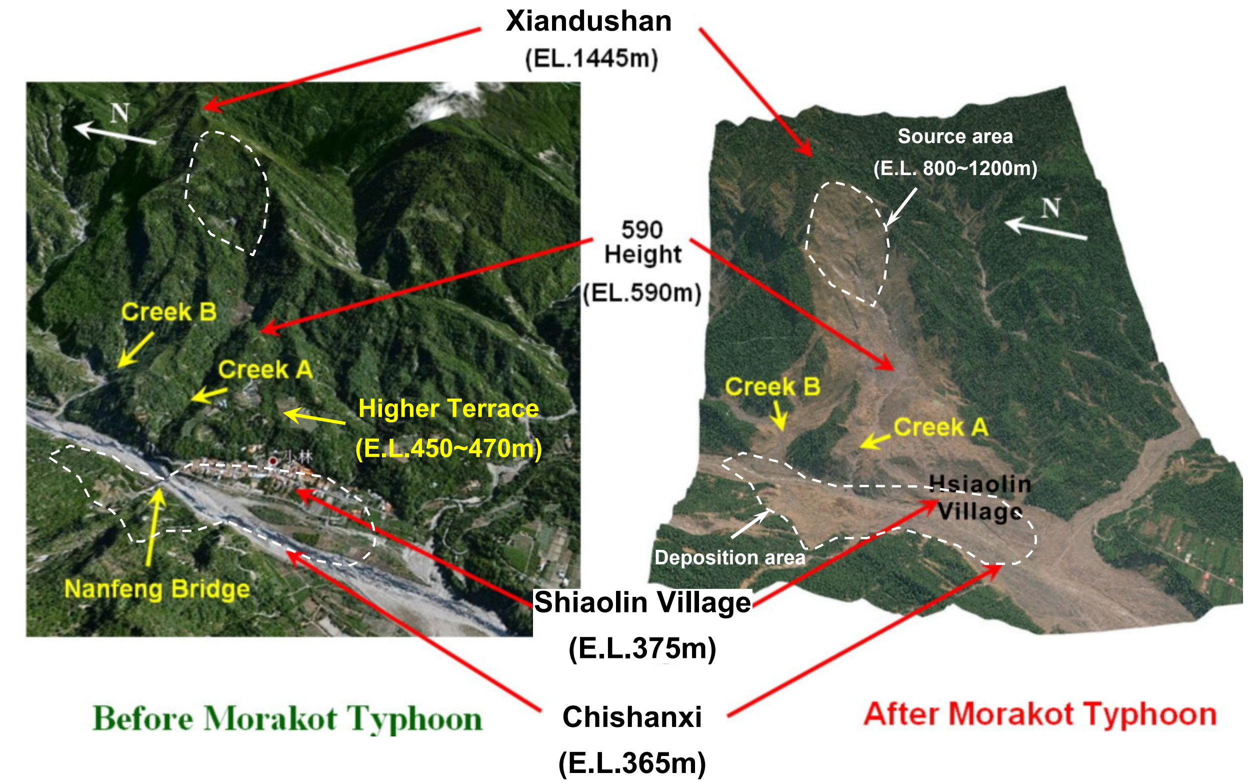
Sinotech Engineering Consultants, INC.
National Taiwan University
National Central University

June 24, 2010

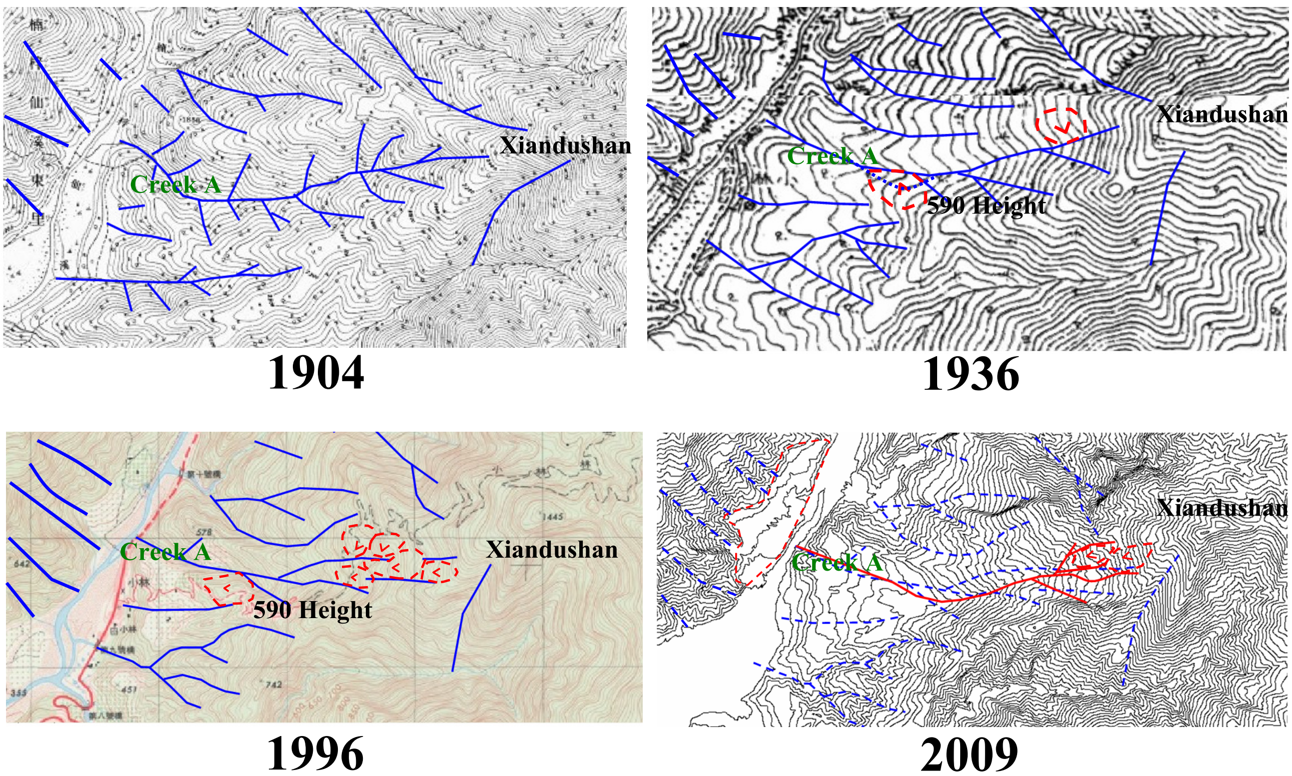
Outline

- ➢Introduction
- ➢Geomorphologic analysis
- ➢Numerical Simulation
- ➢Conclusion

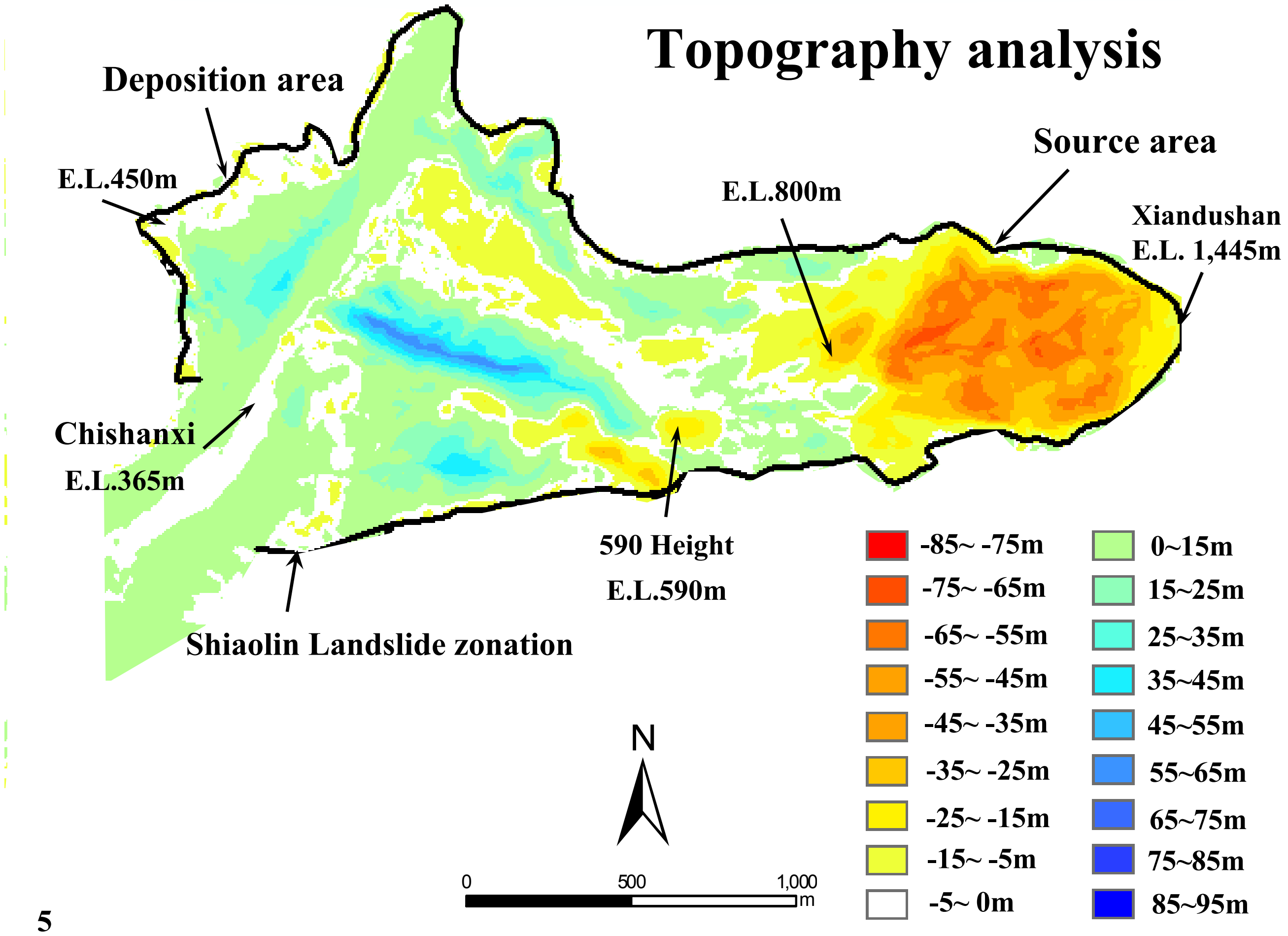
Introduction- Topography of Shiaolin landslide



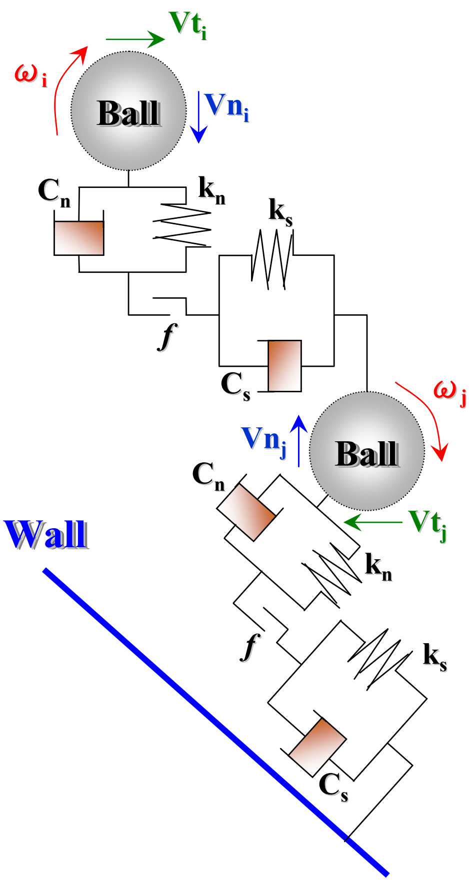
Geomorphologic analysis

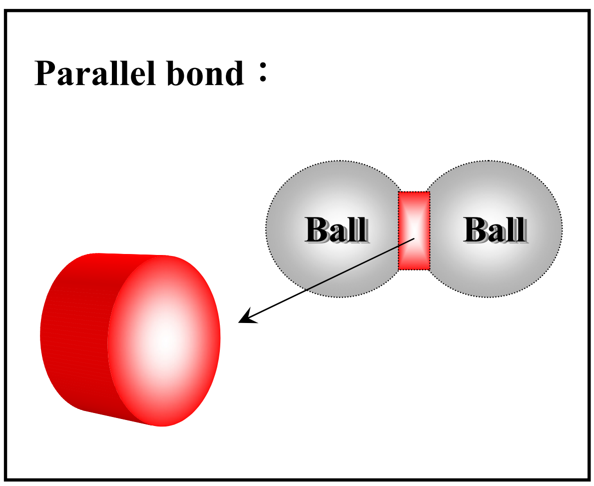


Topography analysis



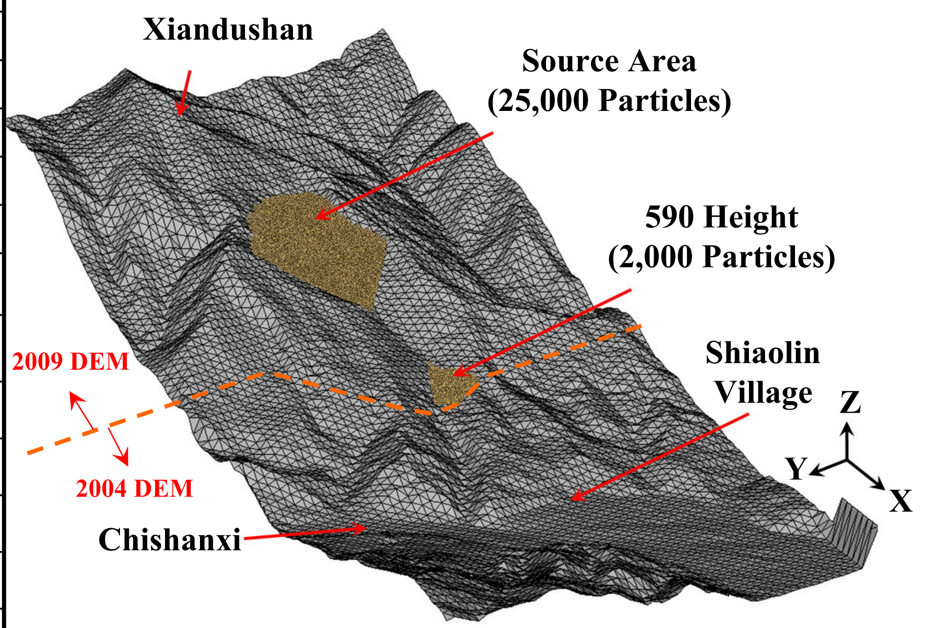
PFC Theory (Discrete Element Method)

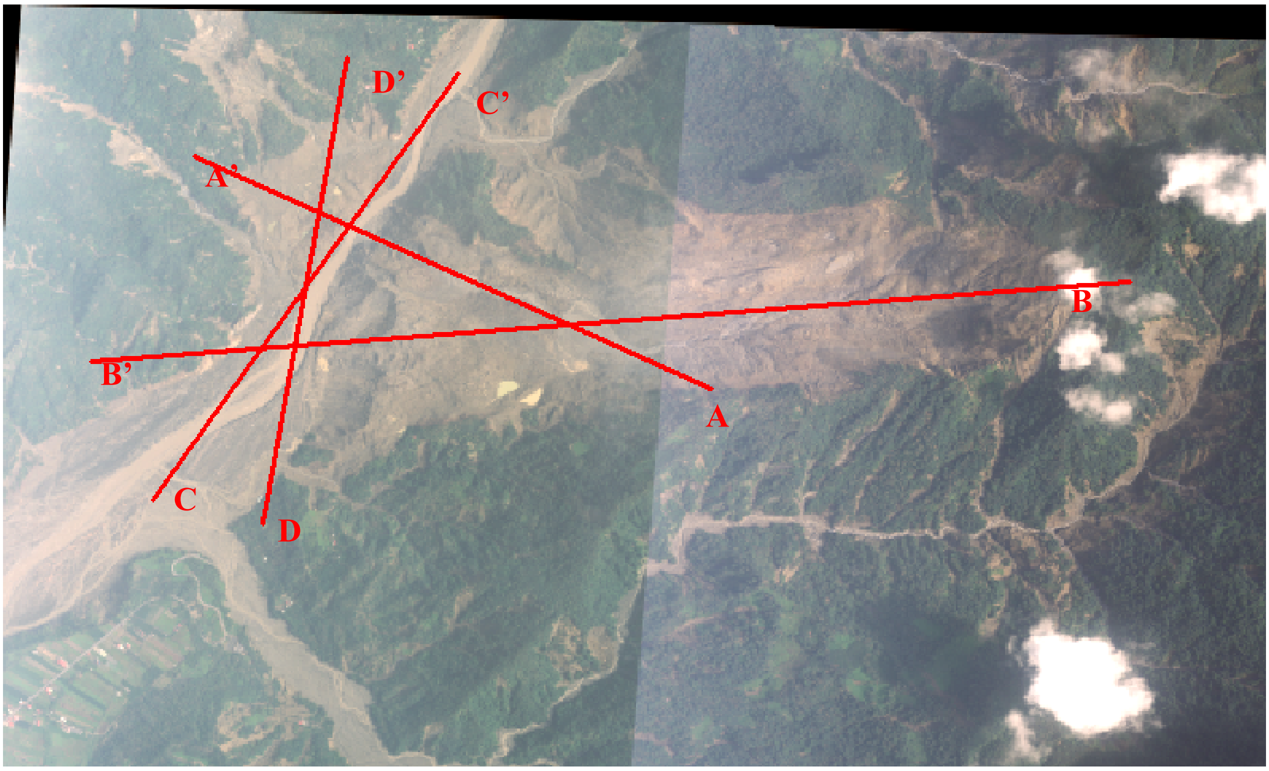


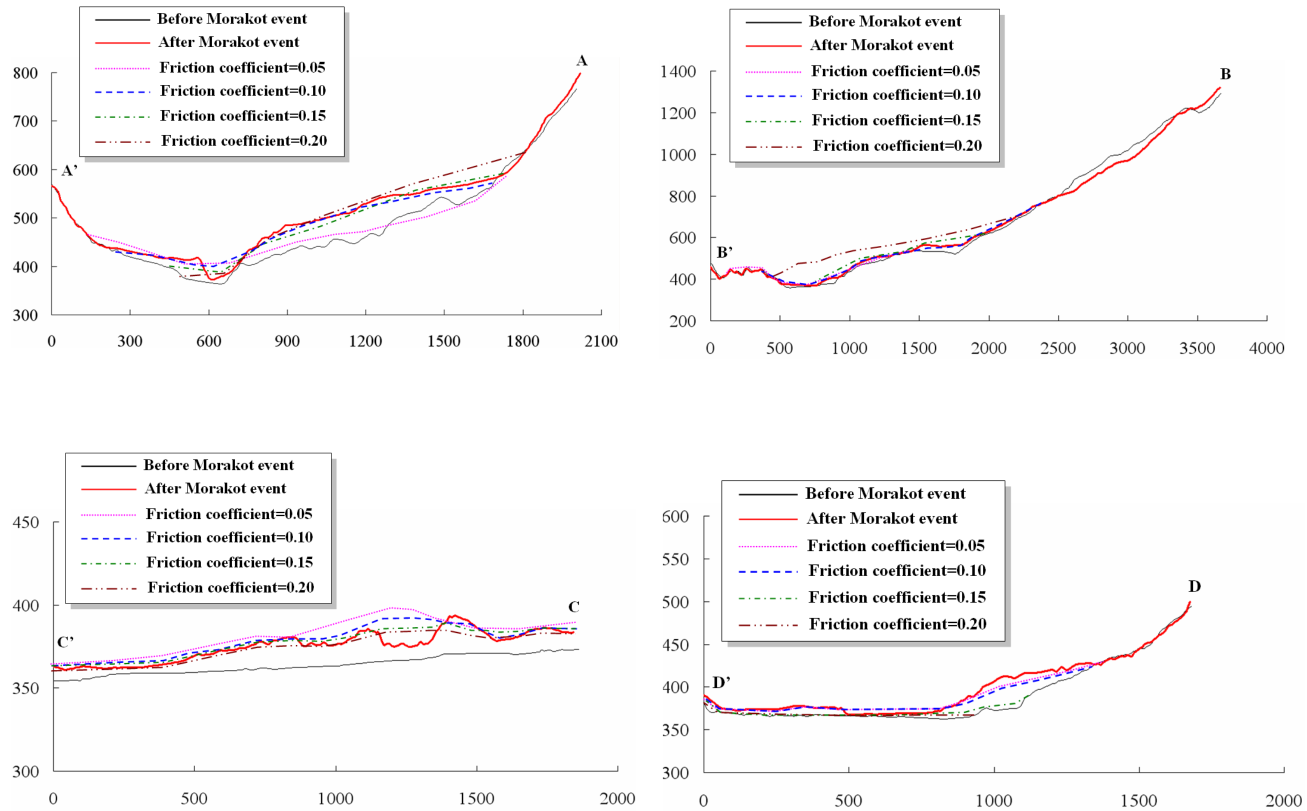


Numerical modeling of Shiaolin landslide

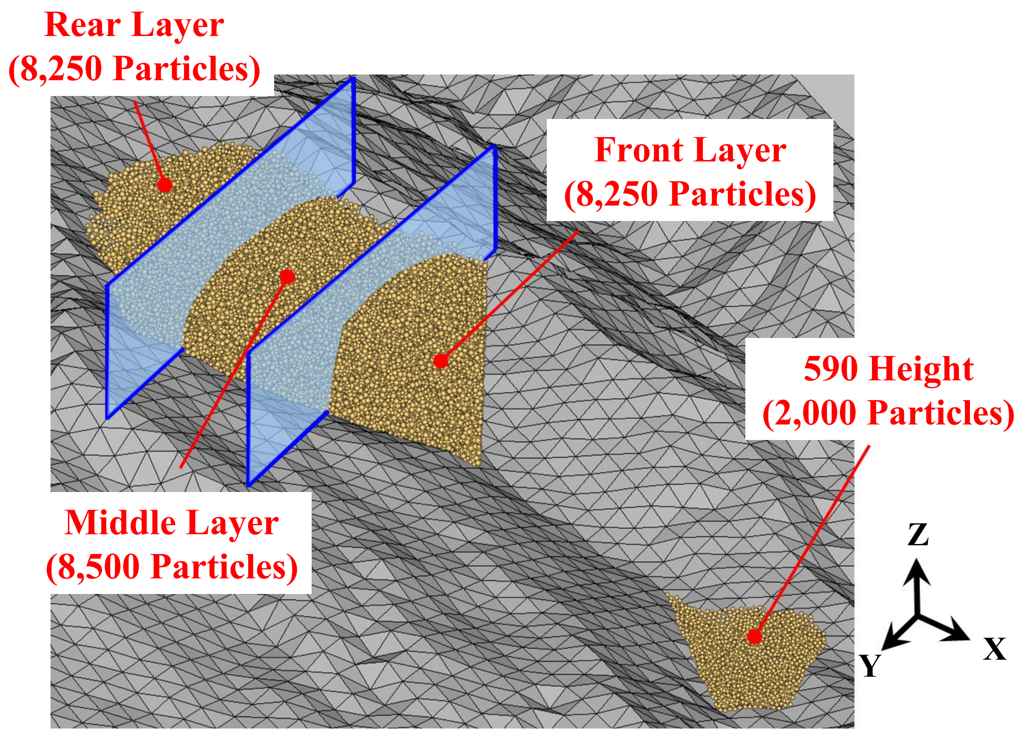
Landslide Volume (m^3)	2.3e8
Number of wall elements	13,456
Number of particles	27,000
Particle density (kg/cm^3)	2,600
Range of particle radius (m)	4~6
Normal stiffness (KN/m)	2e8
Shear stiffness (KN/m)	2e8
Friction coefficient of slip surface for each particle	0.05~0.2
Friction coefficient of wall	0.6
Normal stiffness of parallel bonds (KN/m^3)	2e8
Shear stiffness of parallel bonds (KN/m^3)	2e8
Normal strength of parallel bonds (KN/m^2)	2e6
Shear strength of parallel bonds (KN/m^2)	2e6
Critical damping ratio (Normal direction)	0.4
Critical damping ratio (Shear direction)	0.2

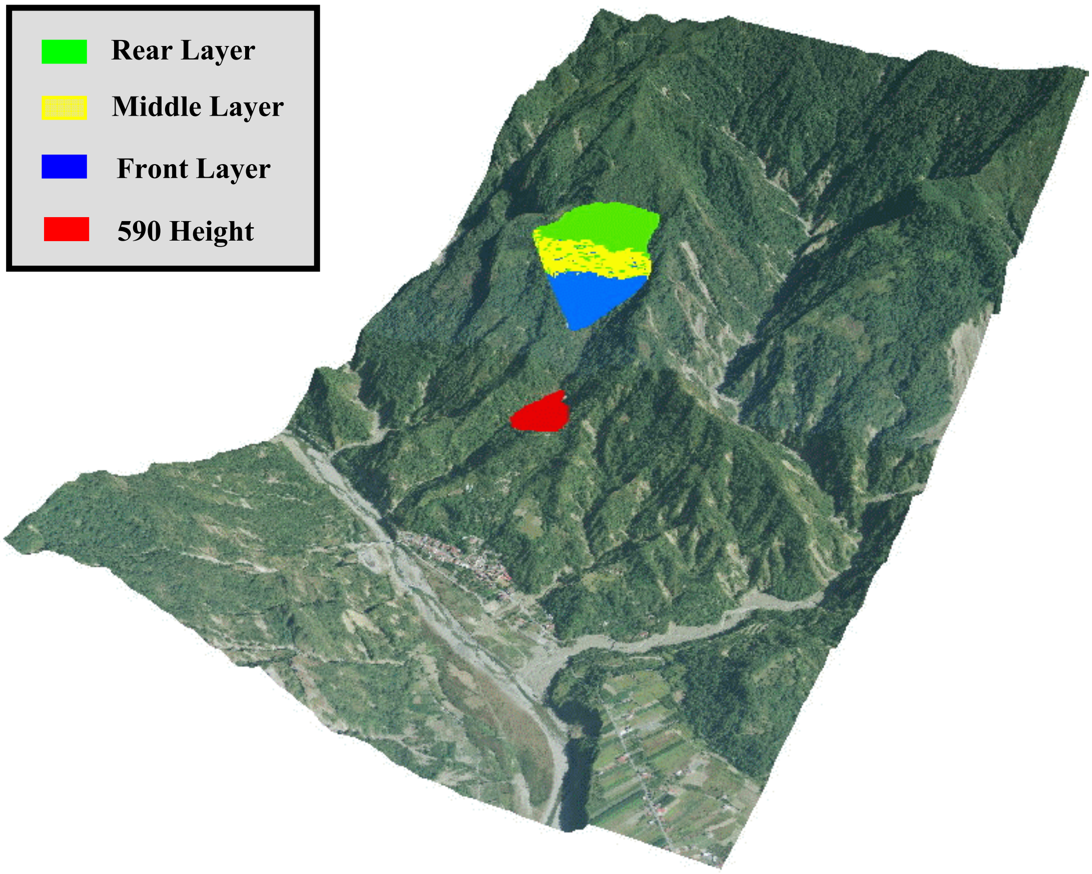


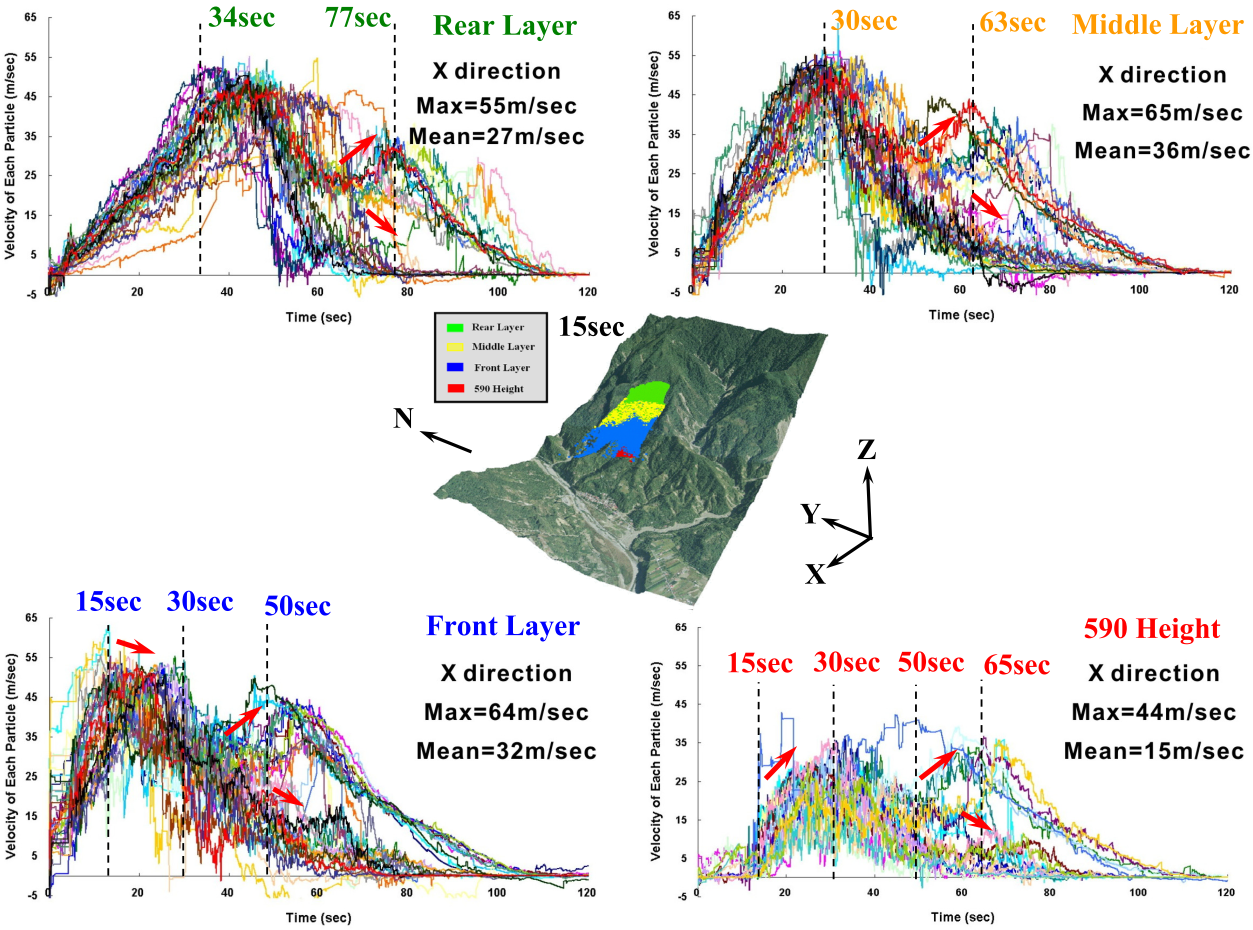


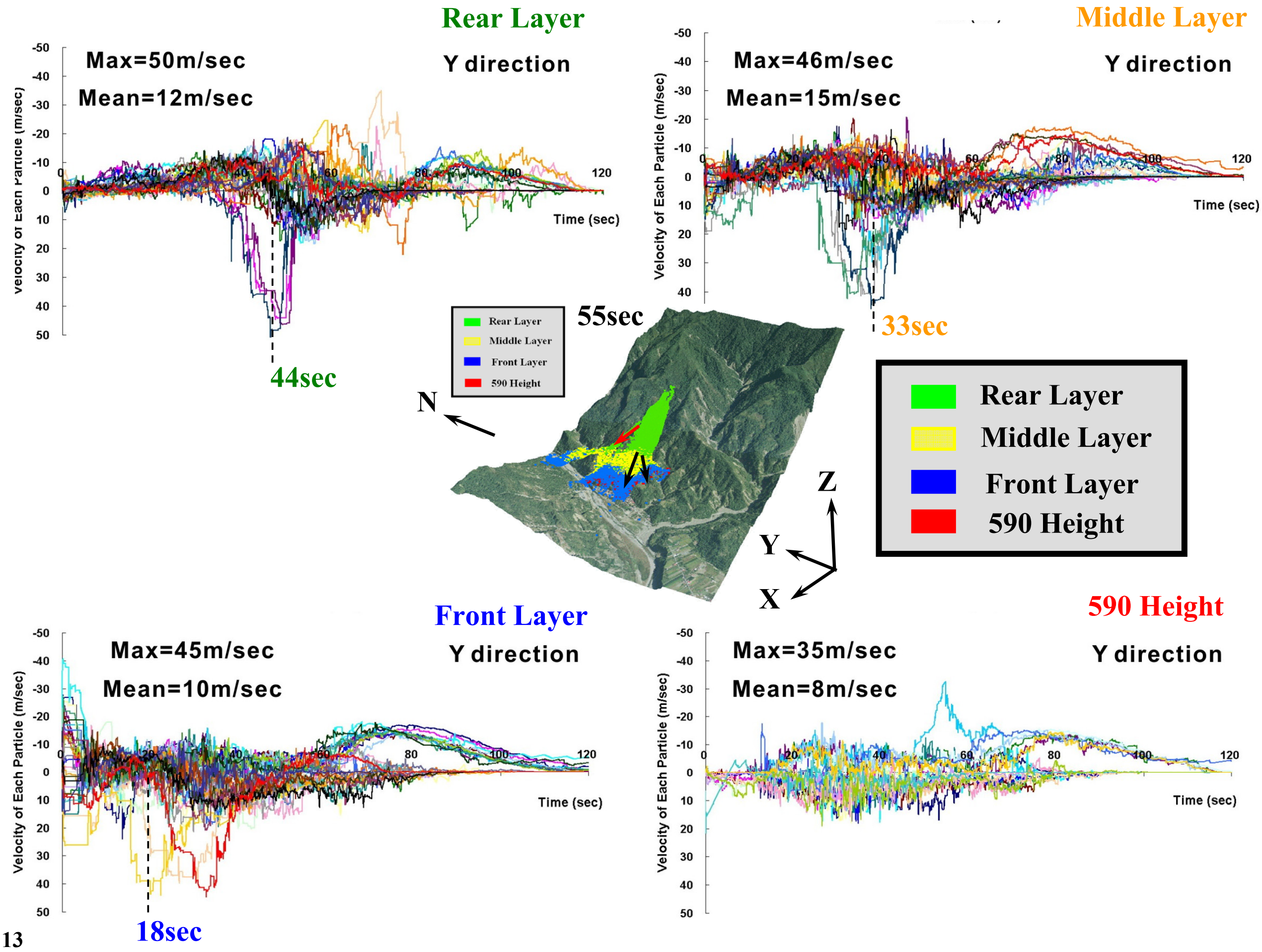


Numerical modeling of Shiaolin landslide

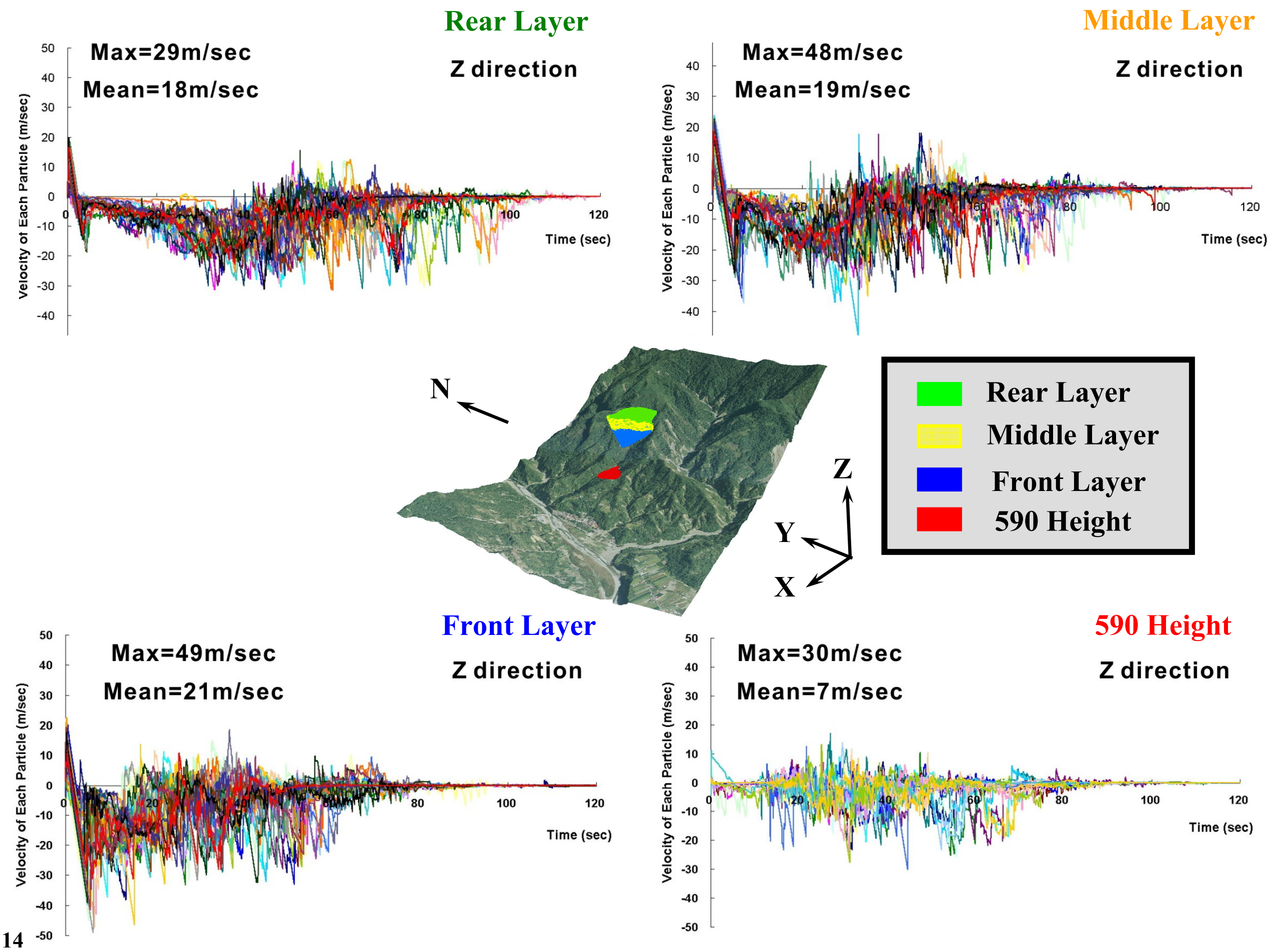



Rear Layer
Middle Layer
Front Layer
590 Height

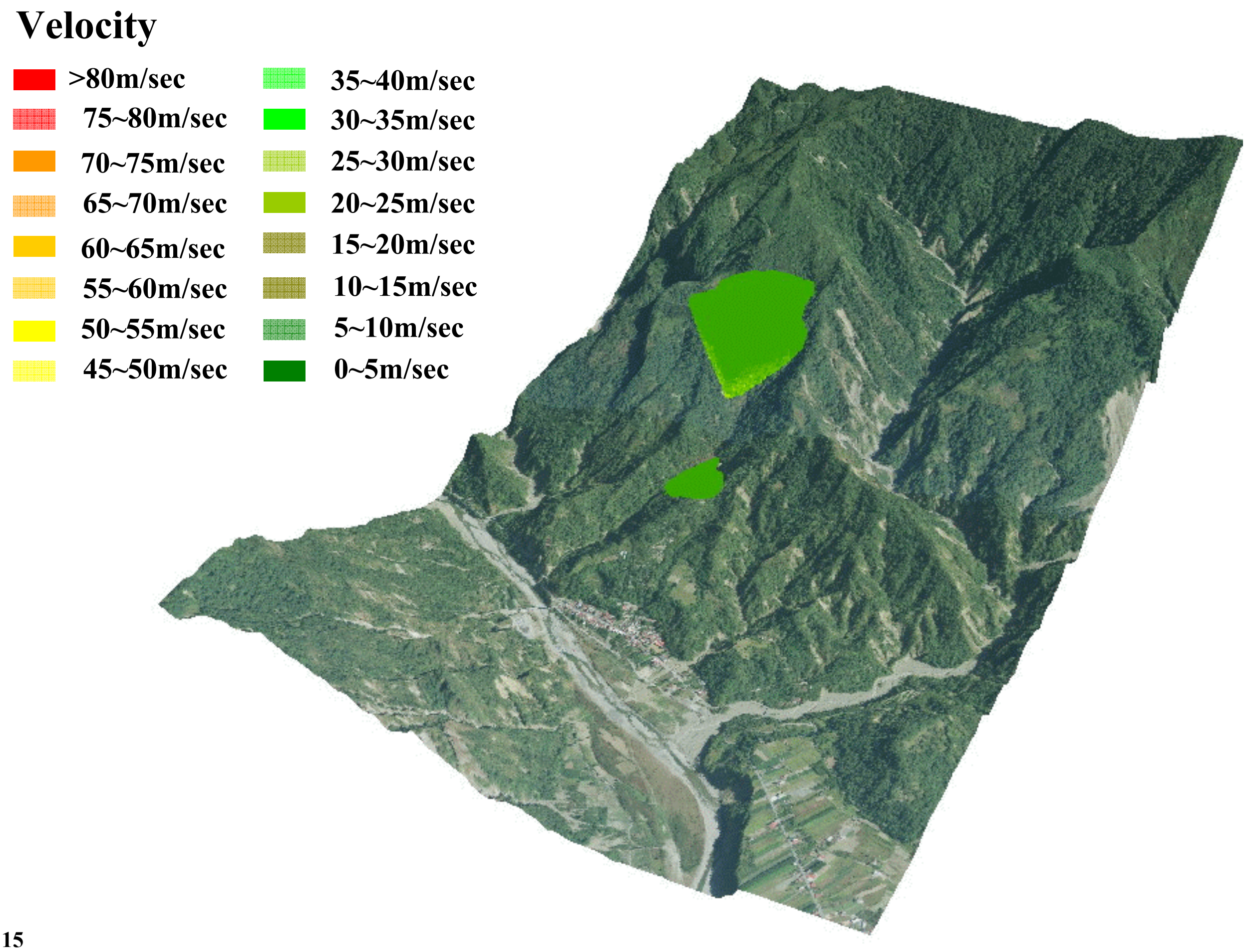

34sec
77sec
Rear Layer
X direction
Max=55m/sec
Mean=27m/sec
Velocity of Each Particle (m/sec)
Time (sec)
30sec
63sec
Middle Layer
X direction
Max=65m/sec
Mean=36m/sec
15sec
Rear Layer
Middle Layer
Front Layer
590 Height
N
Z
Y
X
15sec
30sec
50sec
Front Layer
X direction
Max=64m/sec
Mean=32m/sec
590 Height
15sec
30sec
50sec
65sec
X direction
Max=44m/sec
Mean=15m/sec


Rear Layer
Y direction
Max=50m/sec
Mean=12m/sec
44sec
Middle Layer
Y direction
Max=46m/sec
Mean=15m/sec
33sec
55sec
Rear Layer
Middle Layer
Front Layer
590 Height
N
Z
Y
X
Front Layer
Y direction
Max=45m/sec
Mean=10m/sec
18sec
590 Height
Y direction
Max=35m/sec
Mean=8m/sec
Velocity of Each Particle (m/sec)
Time (sec)

13


Rear Layer
Z direction
Max=29m/sec
Mean=18m/sec
Middle Layer
Z direction
Max=48m/sec
Mean=19m/sec
N
Rear Layer
Middle Layer
Front Layer
590 Height
Z
Y
X
Front Layer
Z direction
Max=49m/sec
Mean=21m/sec
590 Height
Z direction
Max=30m/sec
Mean=7m/sec
Velocity of Each Particle (m/sec)
Time (sec)

14

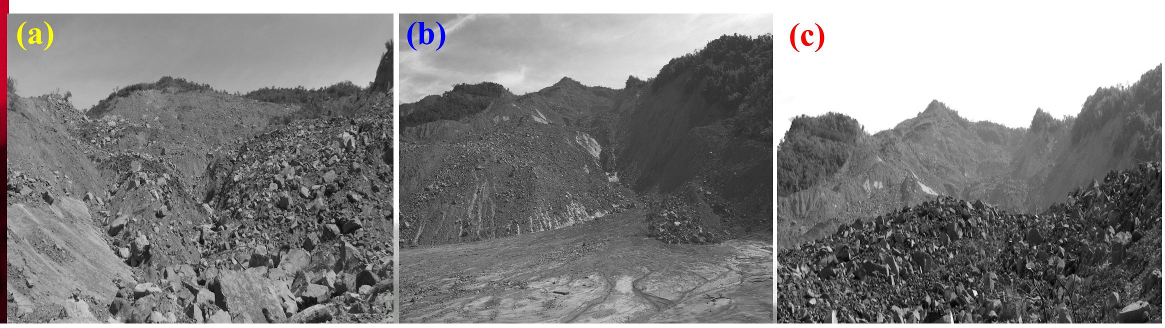


Conclusion

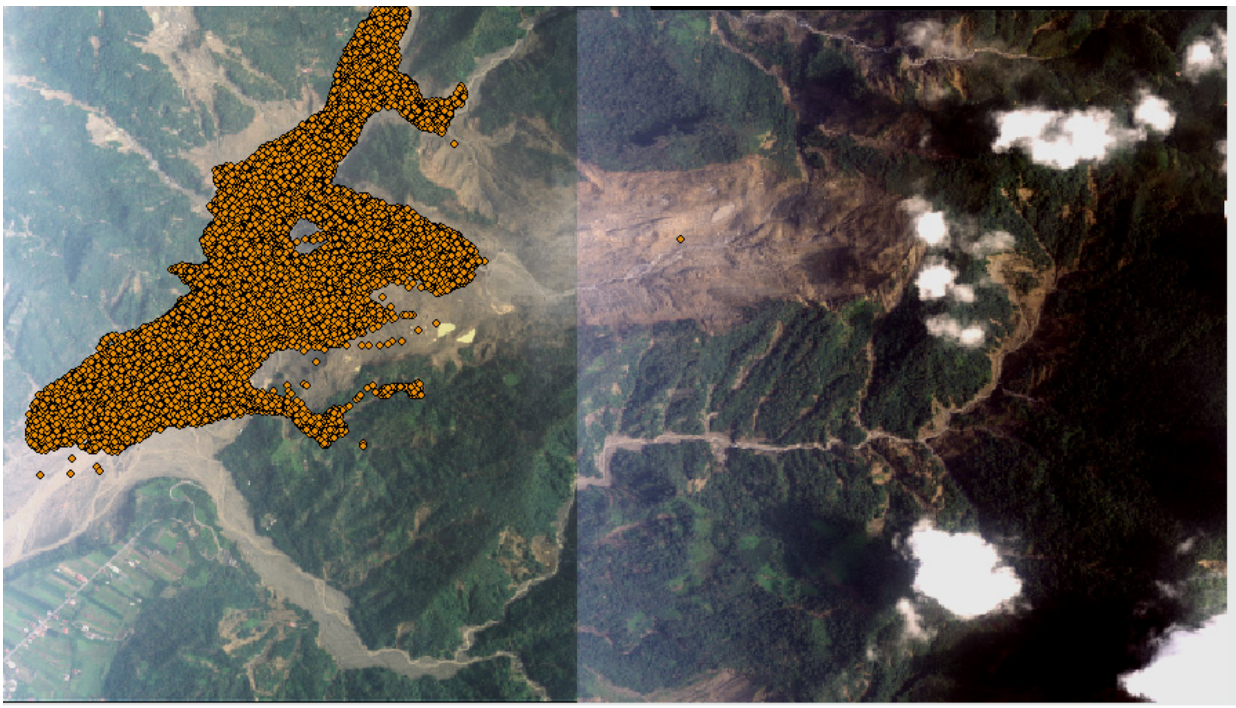
a. **The source area and the top of higher terrace was covered by colluvium of different ages form 1936~2009.**

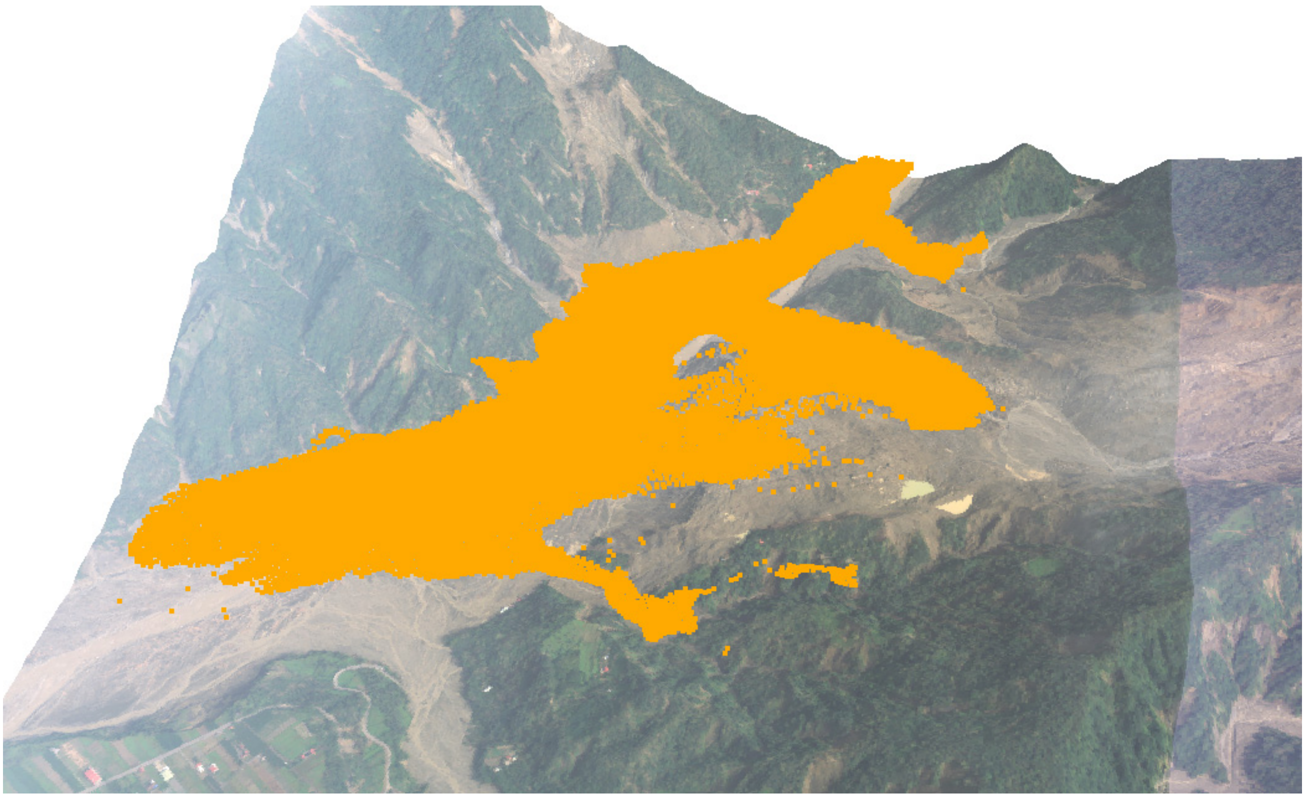
b. **When Shiaolin landslide reached 590 Height from the source area, the steep terrain and the gravity controlled the landslide motion.**

c. **When 590 Height collapsed for Shiaolin catastrophic landslide and caused the hummocky terrain transformed the smooth terrain, which provide the debris avalanche overflow the higher terrace and buried Shiaolin village.**



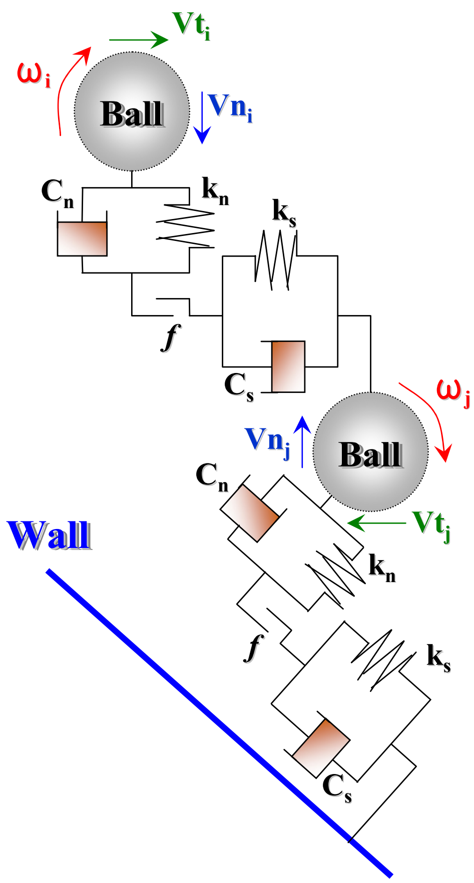
Thanks for Listening

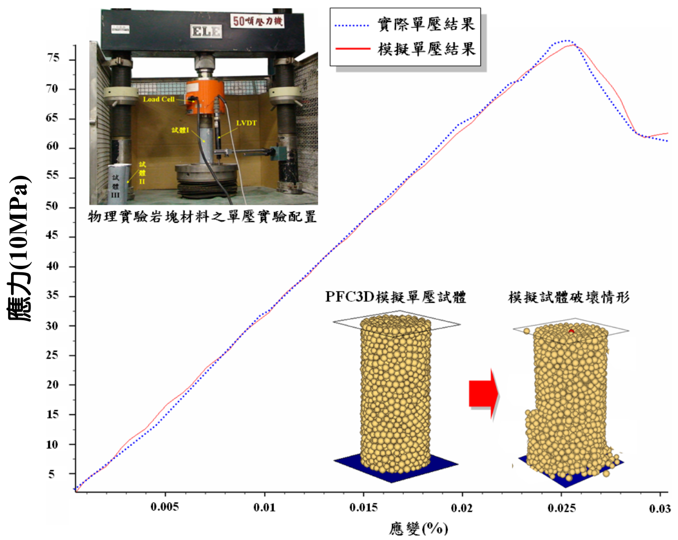


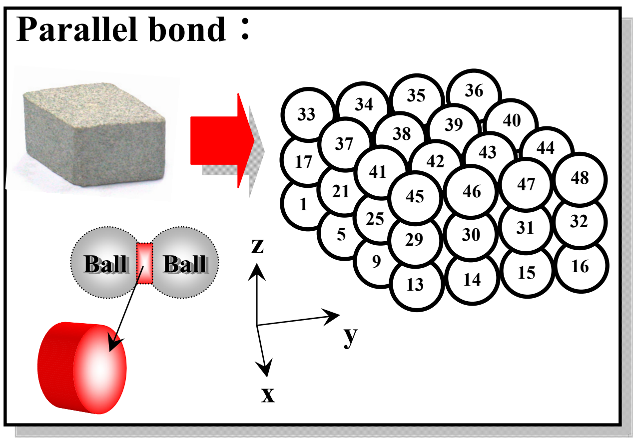


Simulation parameters

PFC 3D 原理:







How to set the parameters?

Material properties:

Density: 2500kg/m^3

Friction angle: 37^o

Particle Size: 0.0005~0.001m

5555 Particles

Simulation Parameters:

Contact Bonds:

Normal Strength (N)

Shear Strength (N)

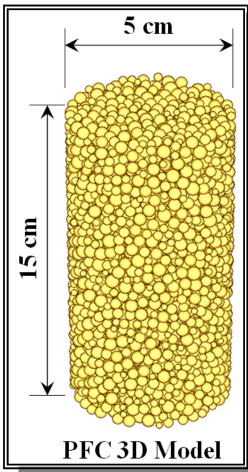
Parallel Bonds:

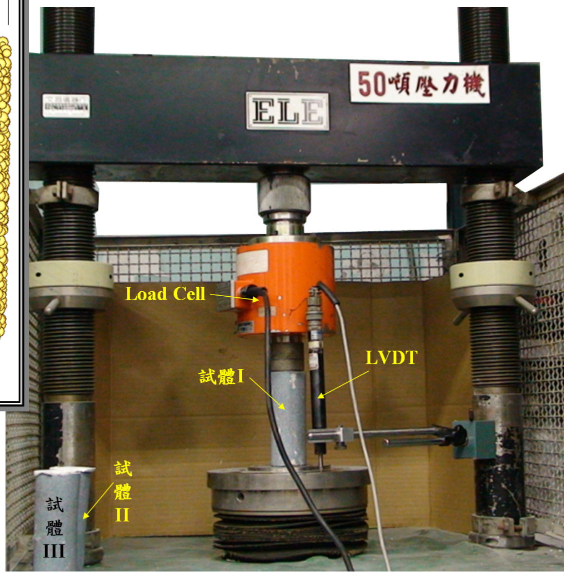
Parallel Bond Stiffness (N/m^3)

Parallel Bond Strength (N/m^3)

Normal Strength (N/m^2)

Shear Strength (N/m^2)





試體單壓配置

PFC（2002）and Potyondy（2004）

Particle Size: 0.0005~0.001m

R=(0.0005+0.001)/2=0.00075
kn=4*R*Ec=4.16*10^7~1.12*10^{8}N/m
Kn/ks=1

Contacts Bond:
kn=4*R*σc=2.5*10^5~5.0*10^{5}N
Kn/ks=1

Parallel Bond:
L=0.0005+0.001=0.0015m
kn=Ec/L=20.8*10^9/0.0015=1.4*10^{13}N/m^3
Kn/ks=1
σc''=T/A+M*R/I—先假設採用0.1σc =12.5MPa
τc''=V/A—先假設採用σc/2 = 6.25MPa

Really Test: (Shi et al., 1994)
Peck Strength=125Mpa
Strain=0.6%
E=20.8GPa

PFC3D Test:
Peck Strength=1554Mpa
Strain=12.4%
E=12.5GPa

實際試驗與PFC3D測試結果

Step=2.2*10^5

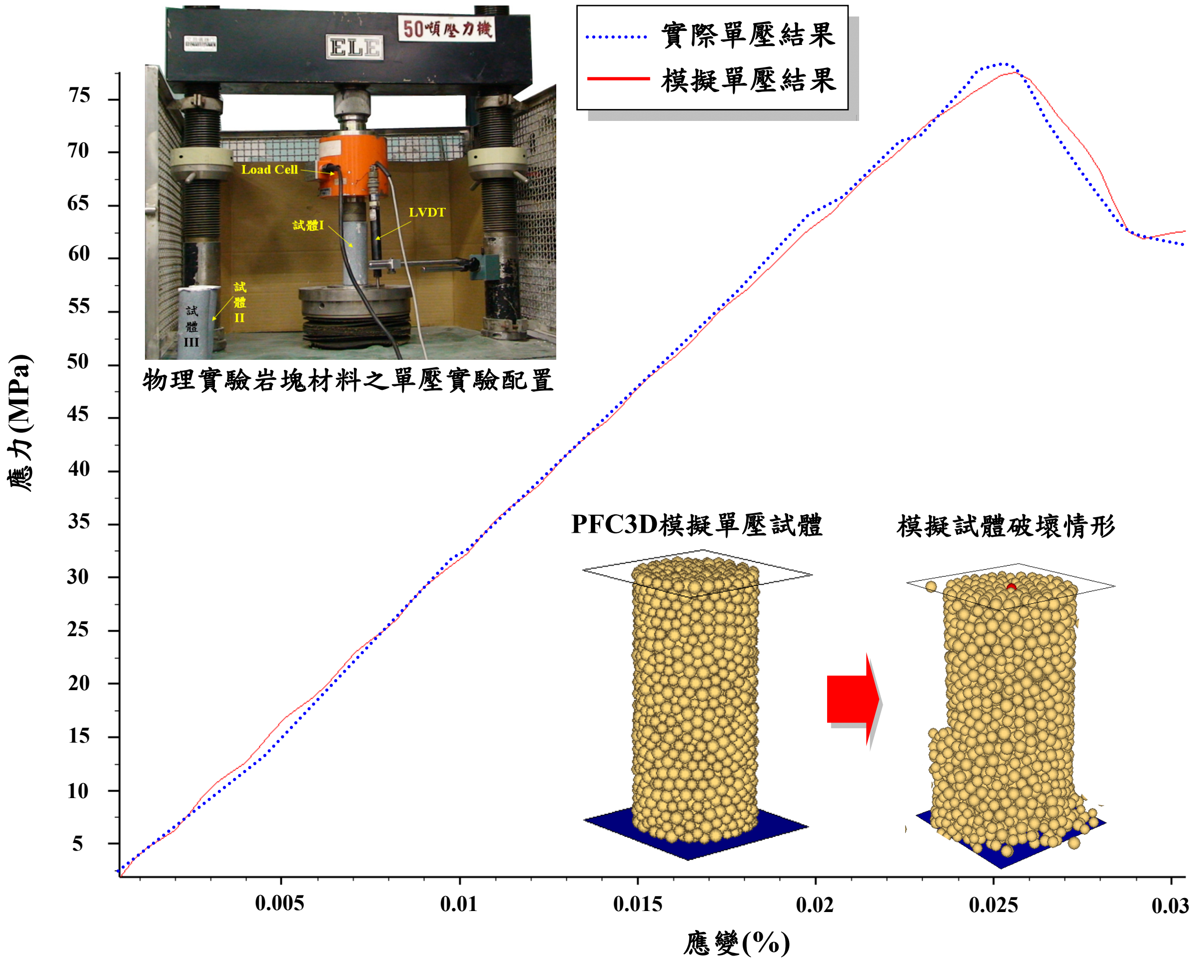
Particle Stiffness:
Normal Stiffness=1*10^8~2*10^{8}N/m
Shear Stiffness=1*10^8~2*10^{8}N/m

Contact Bond:
Normal Contact Bond=2.2*10^3~3.2*10^{3}N
Shear Contact Bond=2.2*10^3~3.2*10^{3}N

Parallel Bond:
Normal Stiffness=1.4*10^{13}N/m^3
Shear Stiffness=1.4*10^{13}N/m^3
Normal Strength=1.25*10^{7}N/m^2
Shear Strength=6.25*10^{6}N/m^2

Really Test: (Shi et al., 1994)
Peck Strength=125Mpa
Strain=0.6%
E=20.8GPa

PFC3D Test:
Peck Strength=122Mpa
Strain=0.62%
E=19.7GPa



實際試驗與PFC3D測試結果

Step=2.2*10^5

Particle Stiffness:
Normal Stiffness=1*10^8~2*10^8N/m
Shear Stiffness=1*10^8~2*10^8N/m

Normal Contact Bond=2.2*10^3~3.2*10^3N
Shear Contact Bond=2.2*10^3~3.2*10^3N

Parallel Bond:
Normal Stiffness=1.4*10^{13}N/m^3
Shear Stiffness=1.4*10^{13}N/m^3
Normal Strength=1.25*10^7N/m^2
Shear Strength=6.25*10^6N/m^2

Really Test: (Shi et al., 1994)
Peck Strength=125Mpa
Strain=0.6%
E=20.8GPa

PFC3D Test
Peck Strength=122Mpa
Strain=0.62%
E=19.7GPa

Test Simulation:
Particle Size: 0.0005~0.001m

Particle Stiffness:
kn=10*R*Ec ; kn/ks=1

Contacts Bond:
kn=0.04*R*σc ;Kn/ks=1

Parallel Bond:
kn=Ec/L ;kn/ks=1
σc''=T/A+M*R/I—假設採用0.1σc
τc''=V/A—假設採用0.5σc

Case Study Simulation:

Particle Size: 0. 5~1.0m

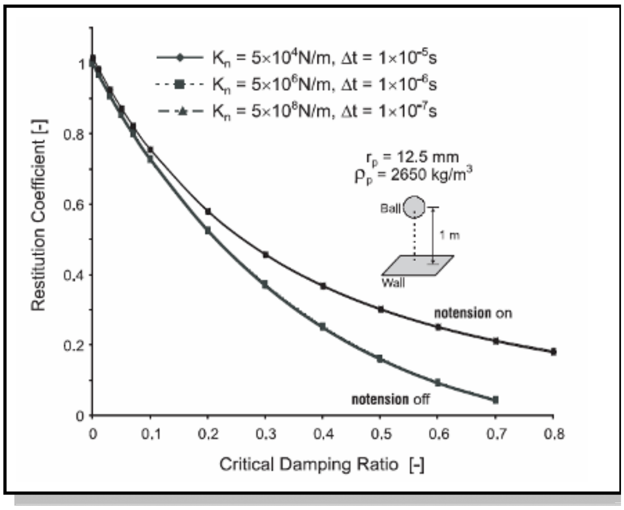
Particle Stiffness:
kn=10*R*Ec=1*10^{11}~2*10^{11}N/m
Kn/ks=1

Contact Bond:
kn=0.04*R*σc=2.5*10^6~5*10^6N
Kn/ks=1

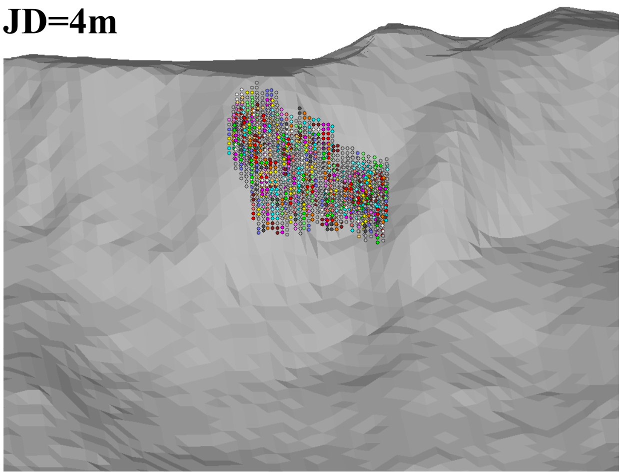
Parallel Bond:
L=0. 5+1=1.5m
kn=Ec/L=1.4*10^{10}N/m^3
Kn/ks=1
σc''=T/A+M*R/I—假設採用12.5MPa
τc''=V/A—假設採用6.25MPa

表 3.7 現地阻尼參數轉換一覽表(改自 Giani, 1992)

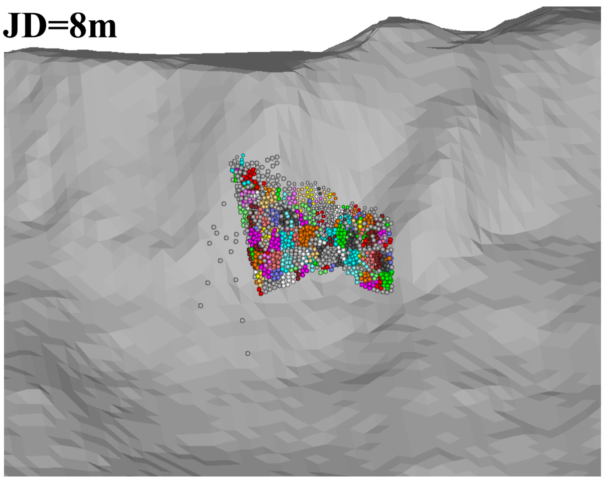
	正向回彈係數	轉換正向阻尼比	切向回彈係數	轉換切向阻尼比
Bedrock	0.50	0.21	0.95	0.02
Bedrock covered by large blocks	0.35	0.32	0.85	0.05
Debris formed by uniform distributed elements	0.30	0.36	0.70	0.11
Soil covered vegetation	0.25	0.40	0.55	0.20



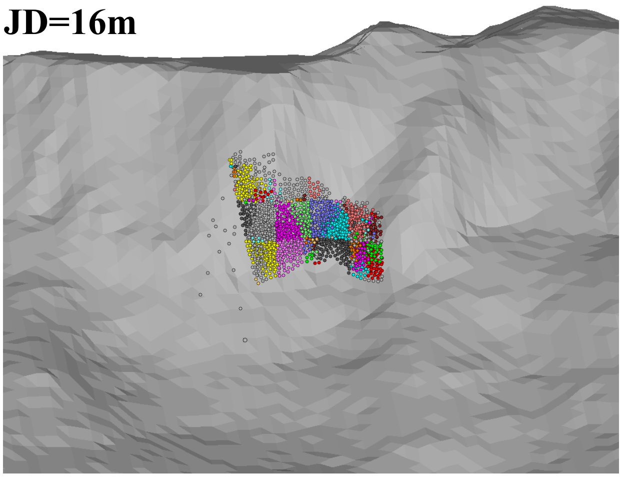
JD=4m



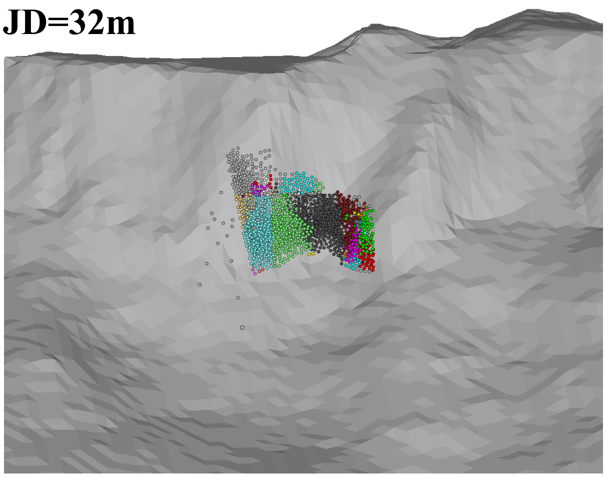
JD=8m



JD=16m



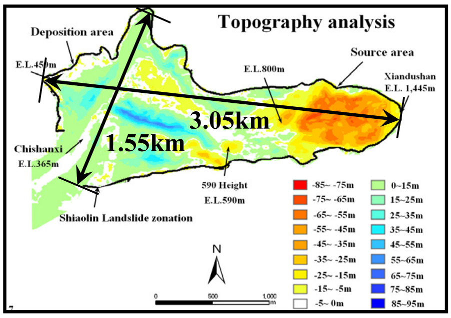
JD=32m

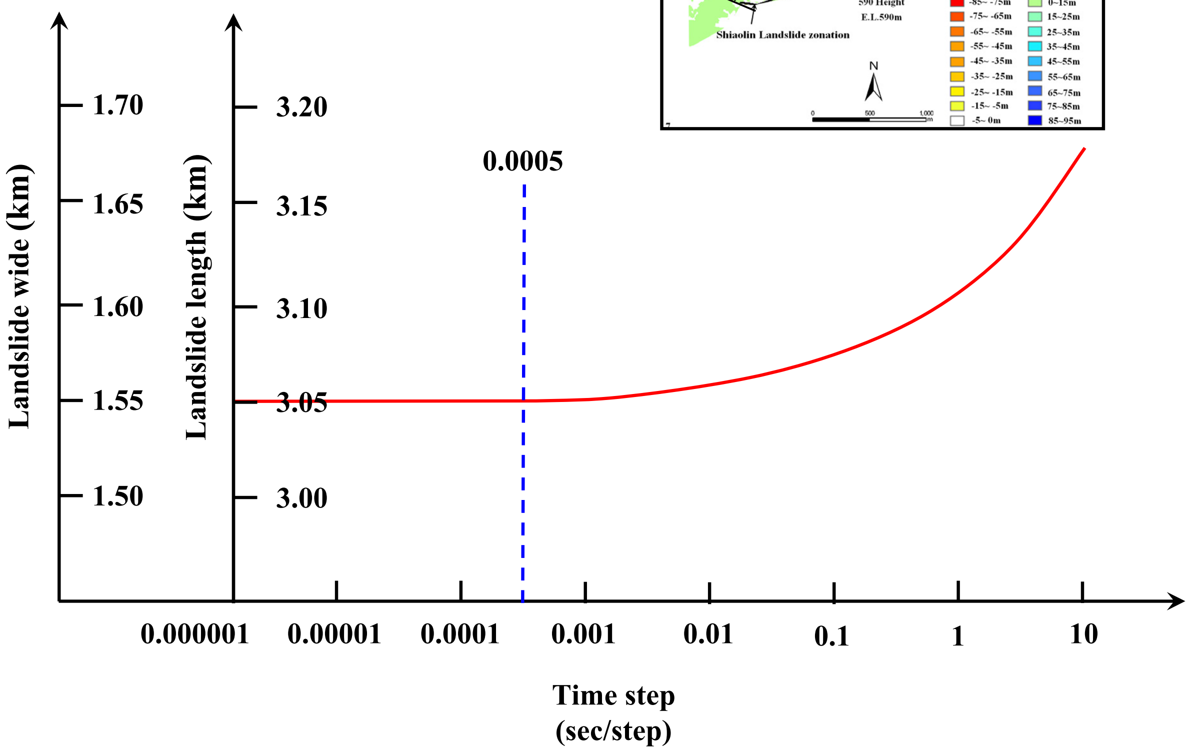


Simulation tests

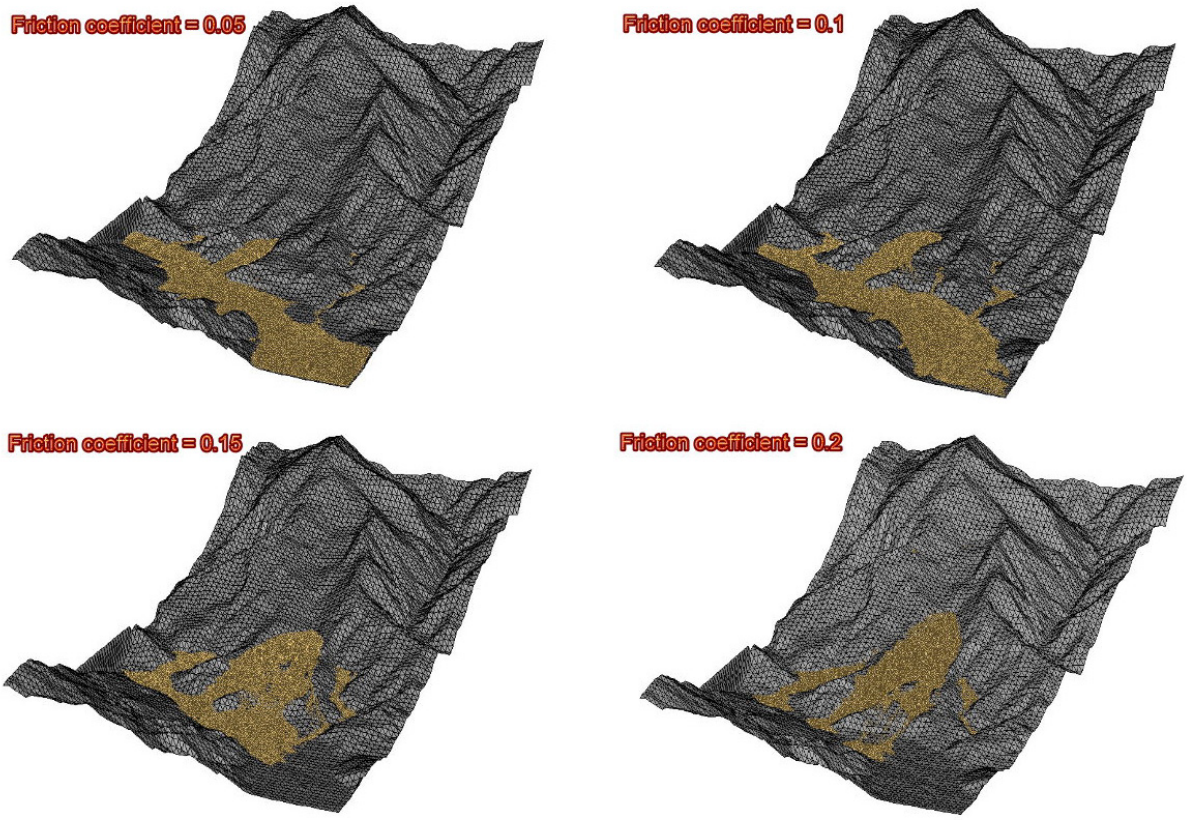
The length of landslide zonation =3.05km

The wide of landslide zonation =1.55km

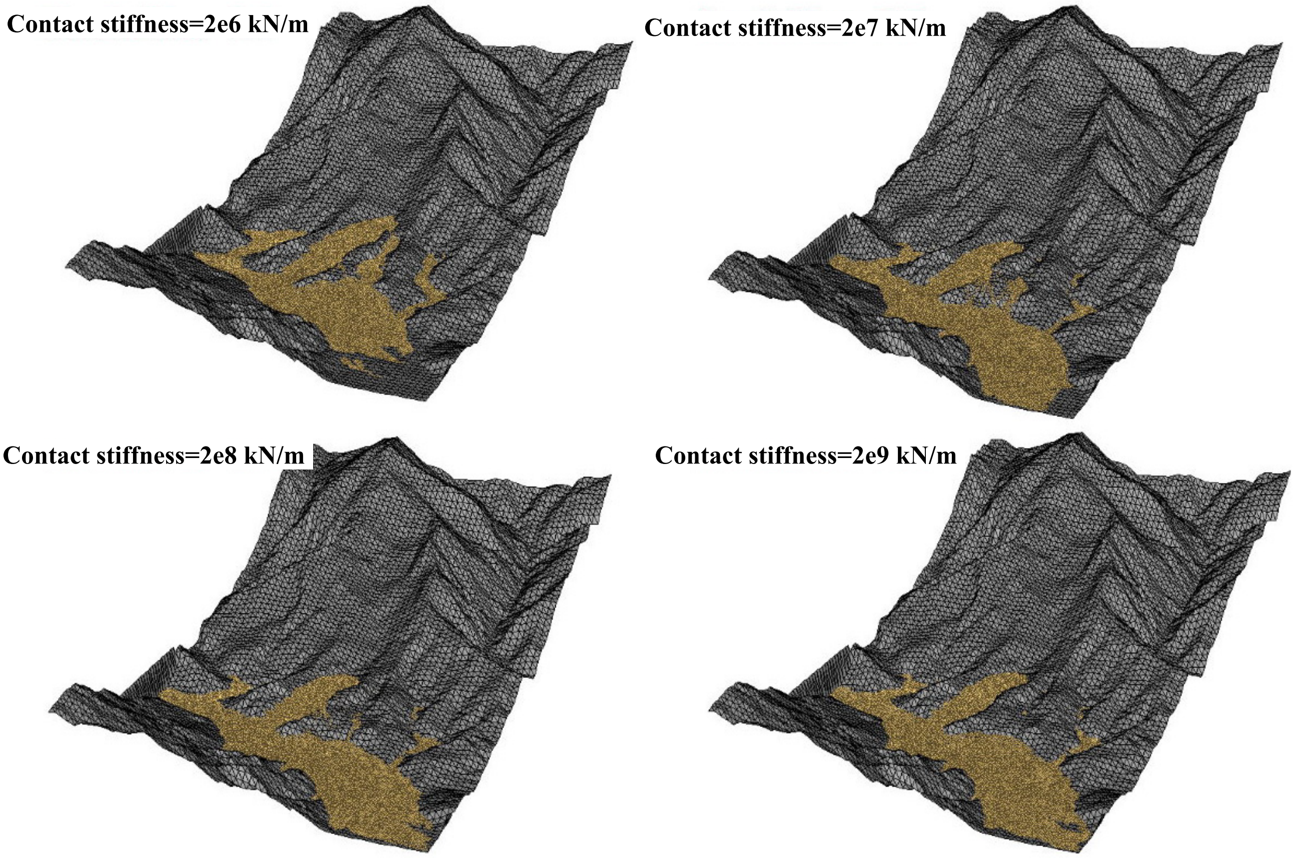


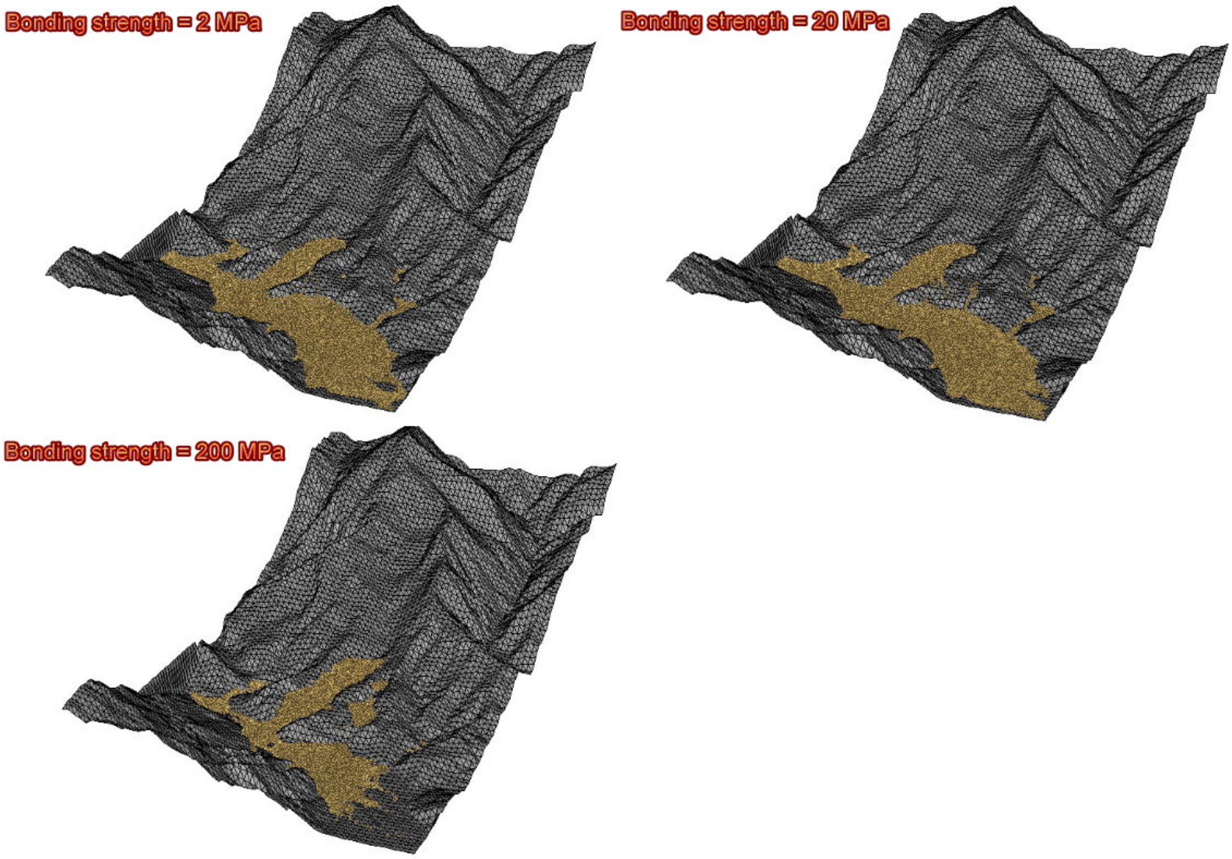


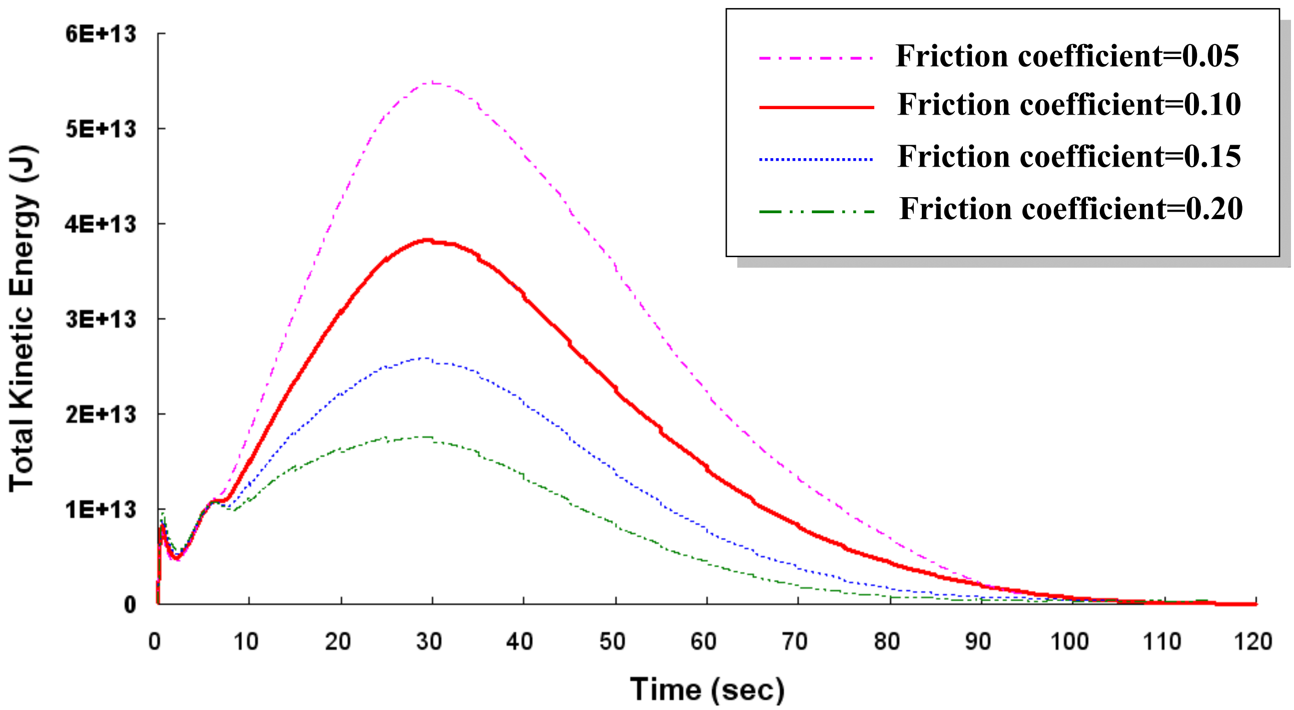
Influence of friction coefficient

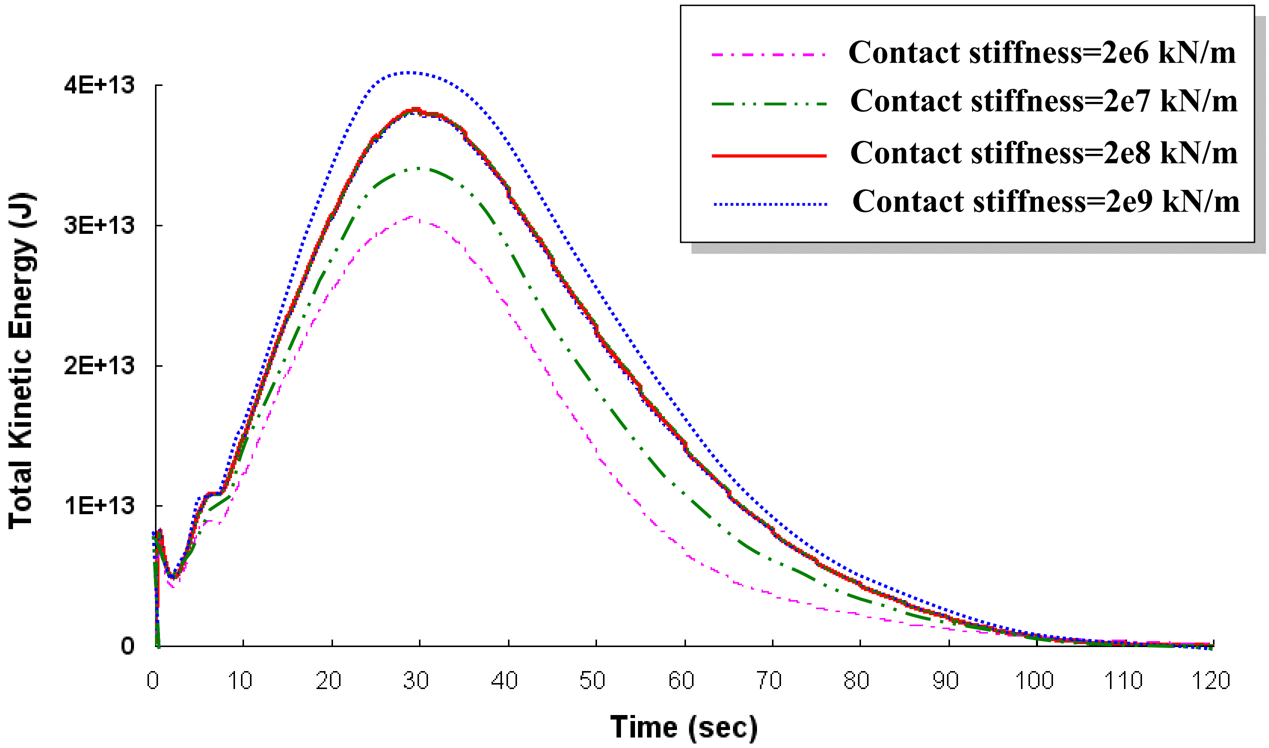


Influence of contact stiffness



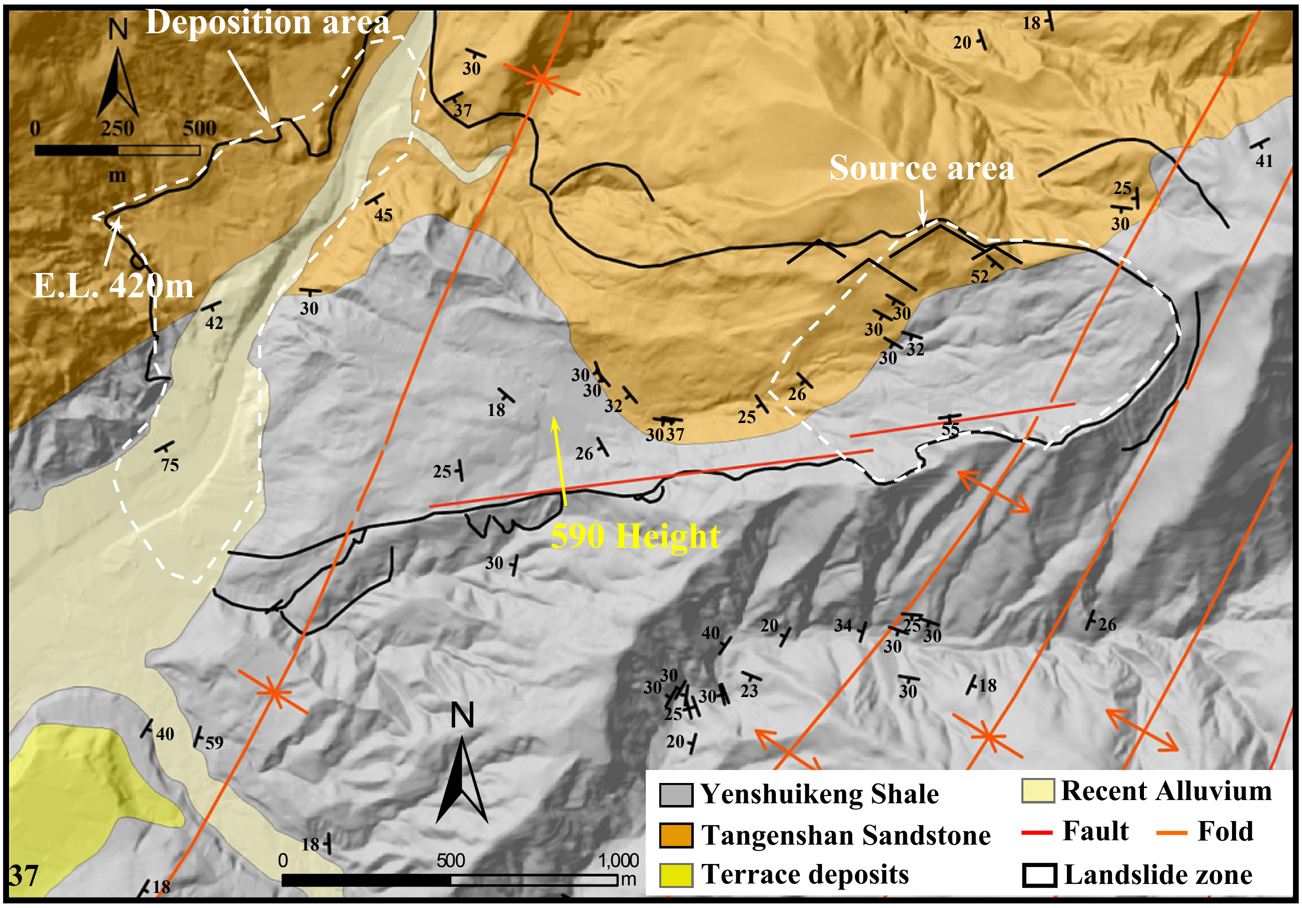

Bonding strength = 2 MPa
Bonding strength = 20 MPa
Bonding strength = 200 MPa


Friction coefficient=0.05
Friction coefficient=0.10
Friction coefficient=0.15
Friction coefficient=0.20
Total Kinetic Energy (J)
6E+13
5E+13
4E+13
3E+13
2E+13
1E+13
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (sec)

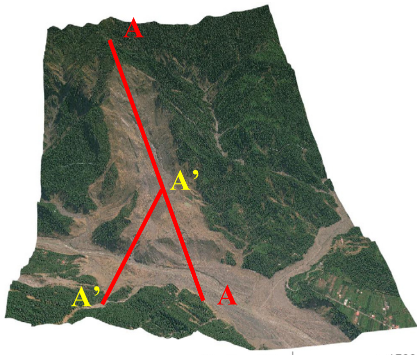

Contact stiffness=2e6 kN/m
Contact stiffness=2e7 kN/m
Contact stiffness=2e8 kN/m
Contact stiffness=2e9 kN/m
Total Kinetic Energy (J)
4E+13
3E+13
2E+13
1E+13
0
0
10
20
30
40
50
60
70
80
90
100
110
120
Time (sec)

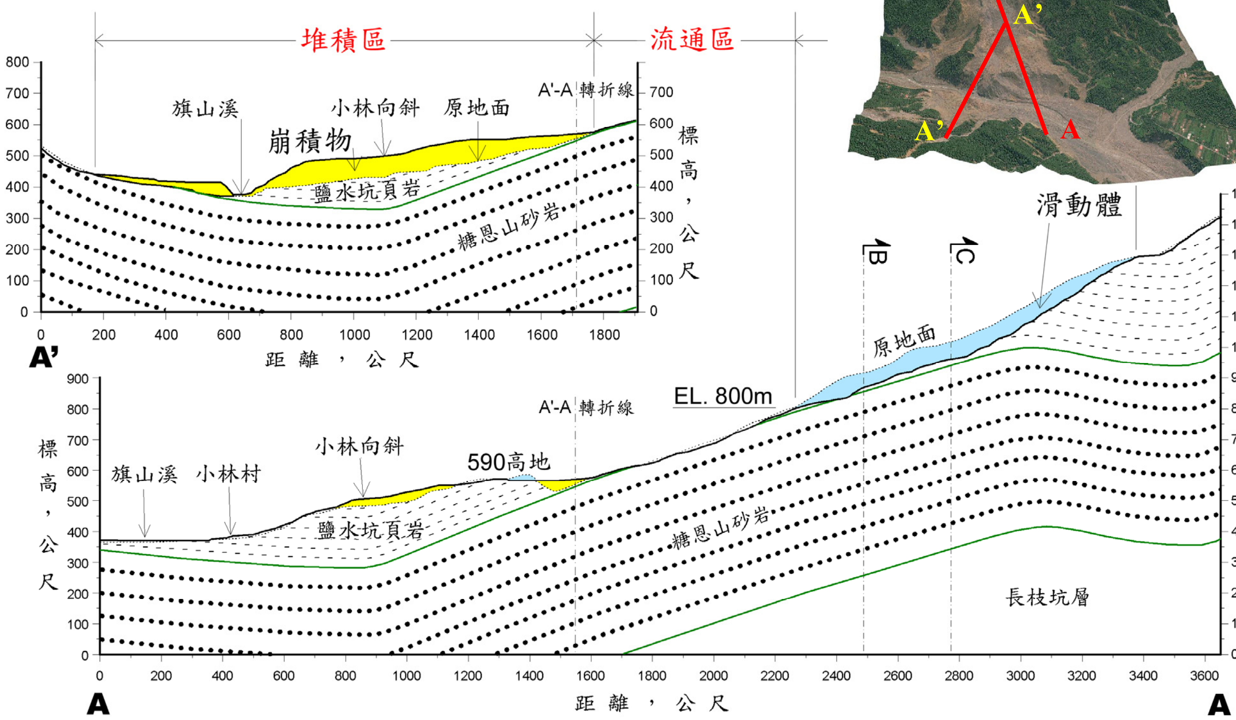
Geology

Introduction- Geologic map (Lee et al., 2010)



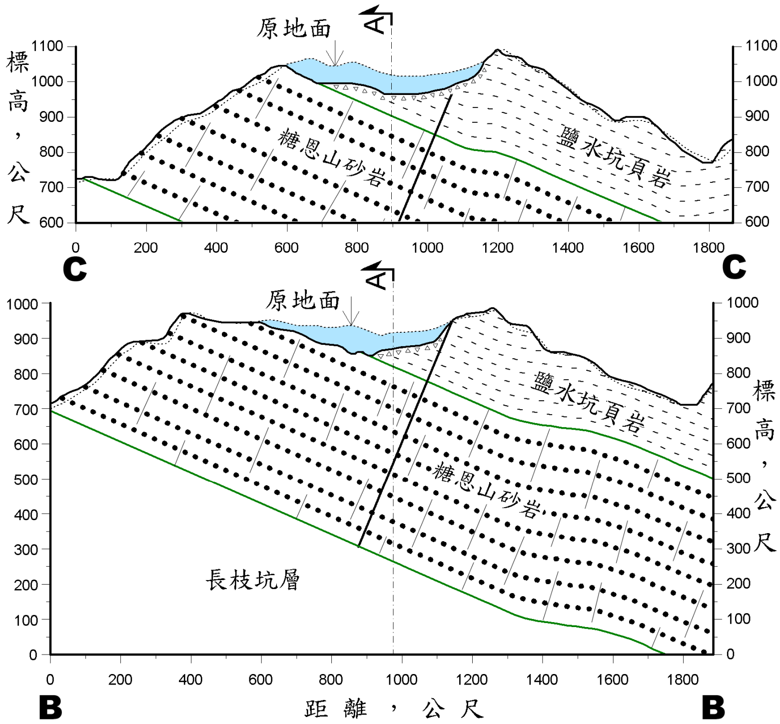
環境地質條件-地質



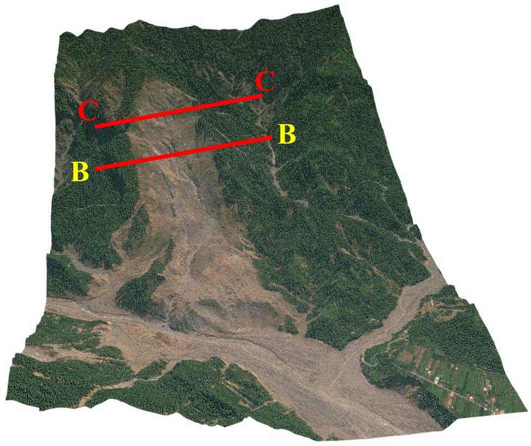


小林村地質剖面圖A–A ， A’–A’ 切在無名溪A附近，堆積厚度厚

環境地質條件-地質剖面



小林村地質剖面圖B–B & C–C

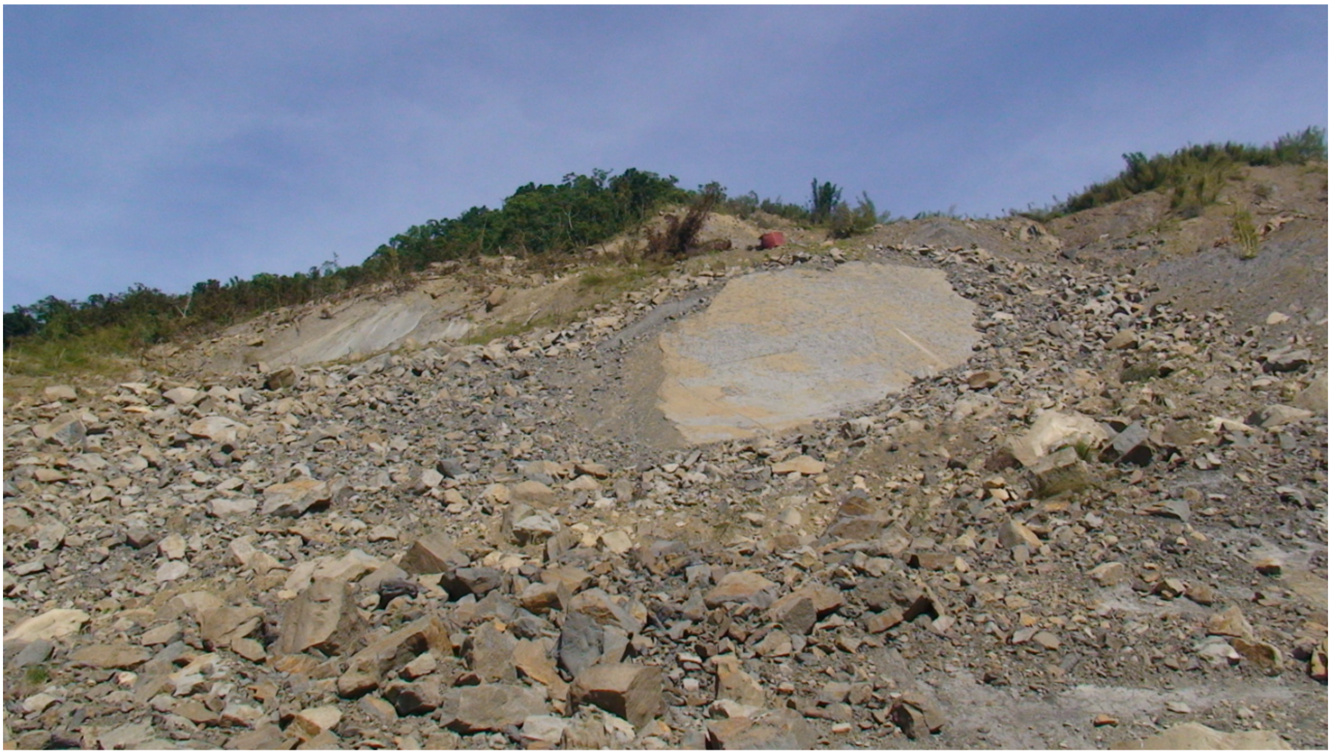


Introduction

Before Morakot Typhoon (2003)

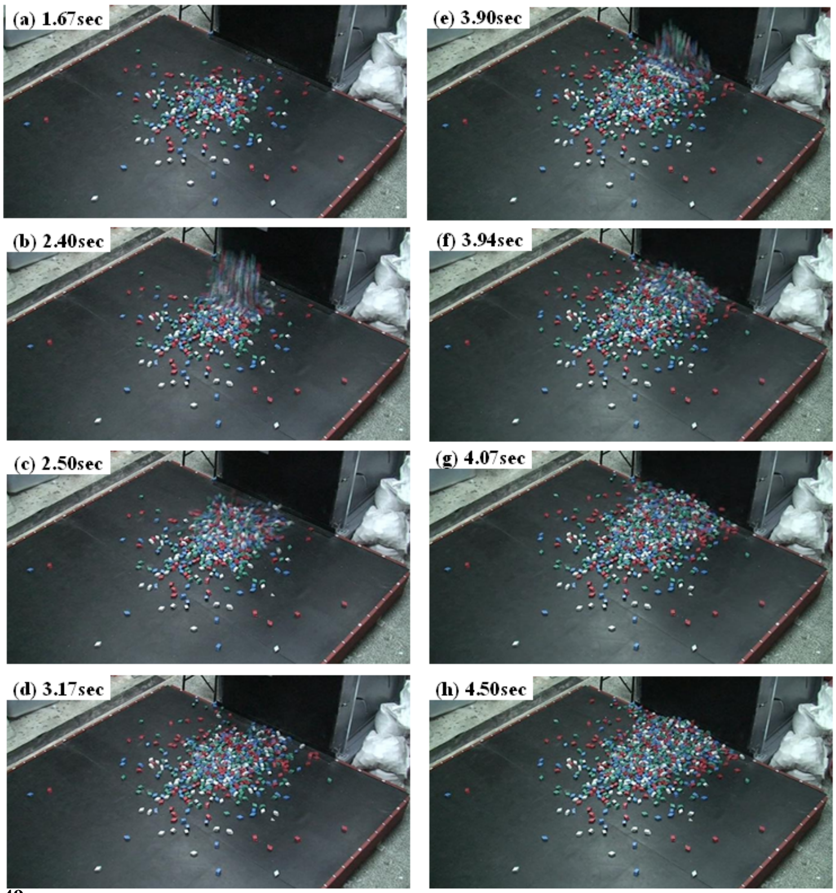
After Morakot Typhoon (2009)

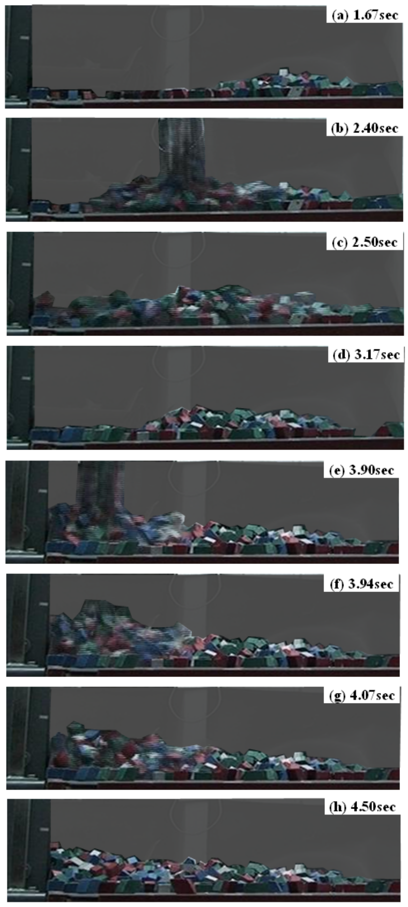
Field investigate



Experiment

90度 地 3 (360) 堆積





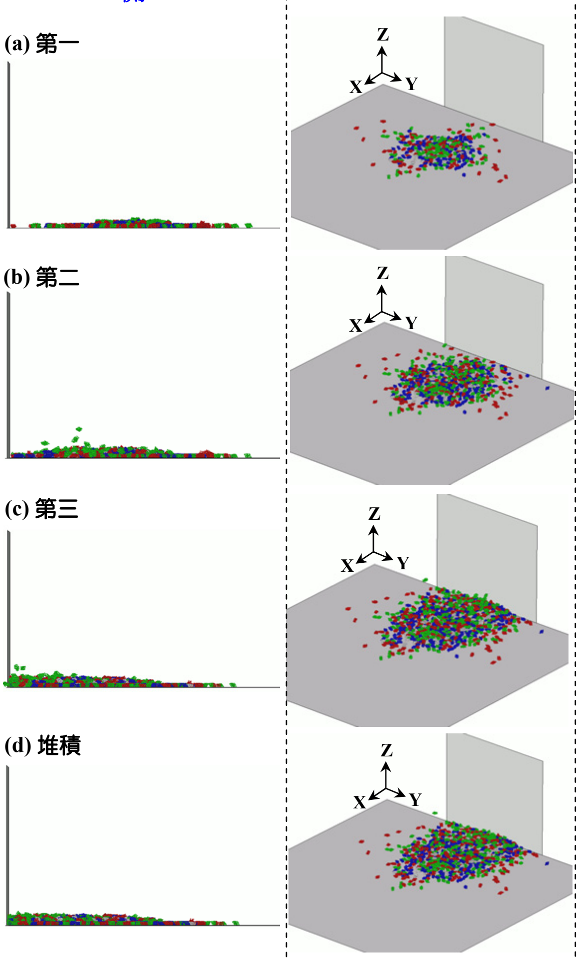
側

(a) 第一

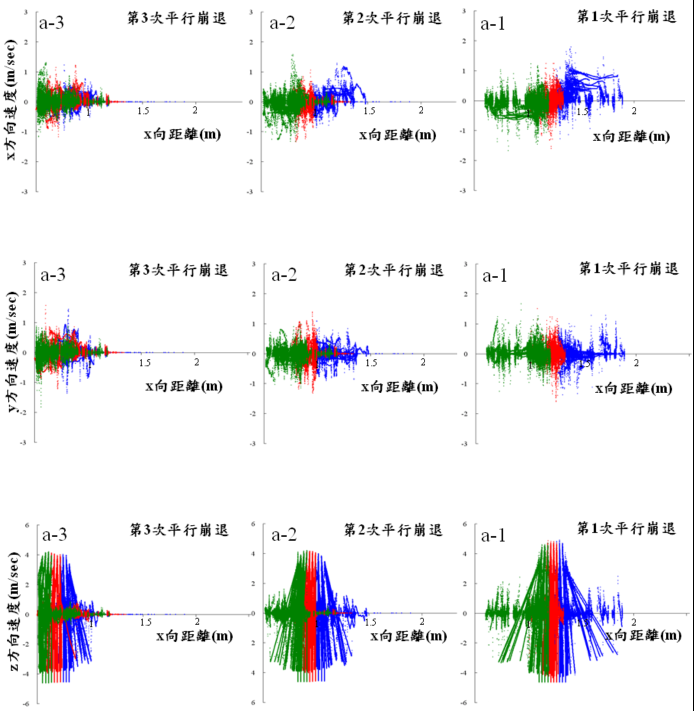
(b) 第二

(c) 第三

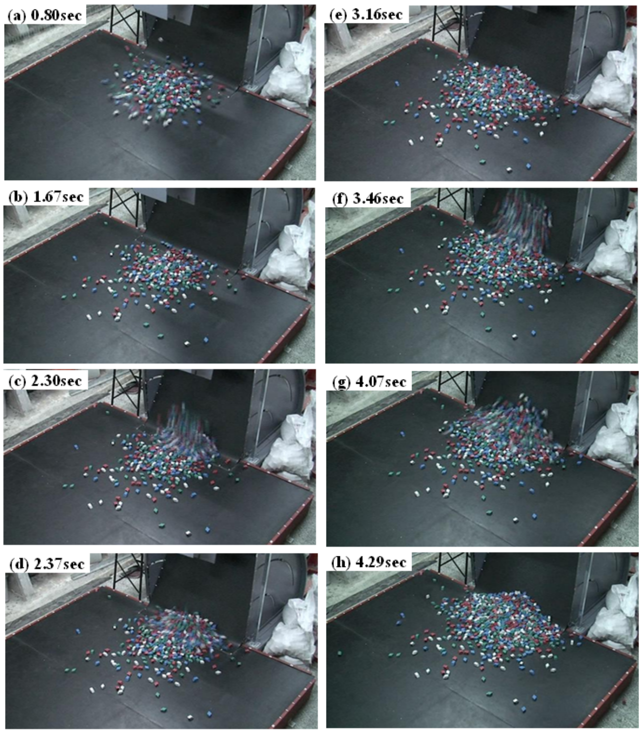
(d) 堆積

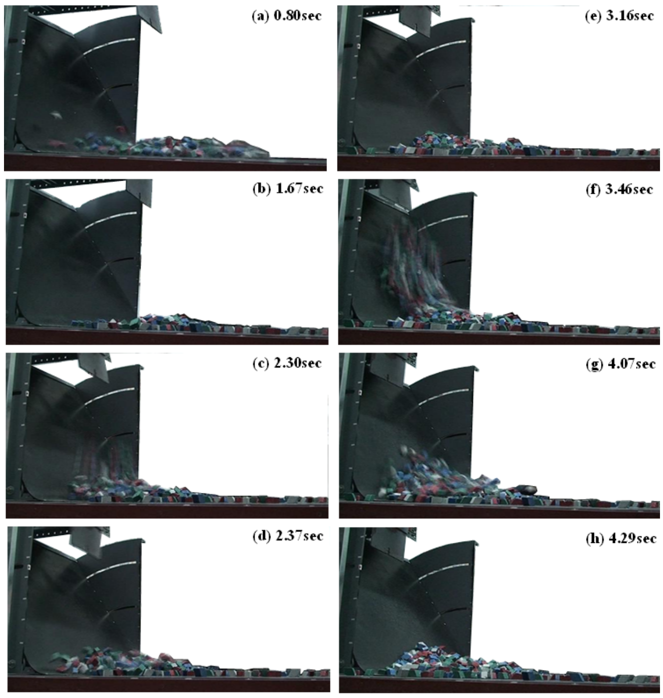


90度 地 3 度 圖



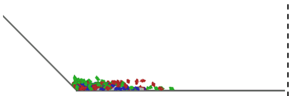
45度 地 3 (360) 堆積

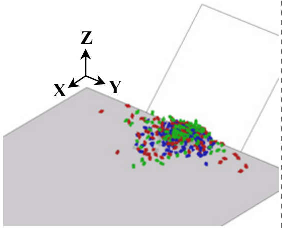




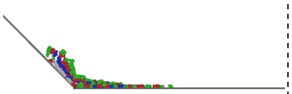
側

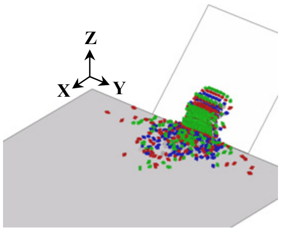
(a) 第一



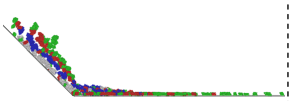


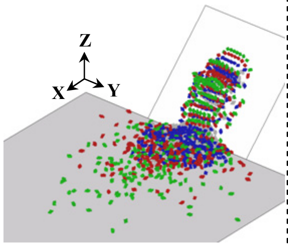
(b) 第二



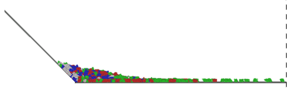


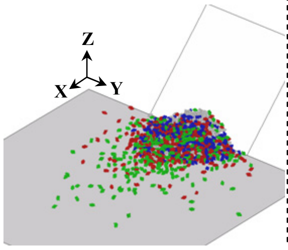
(c) 第三



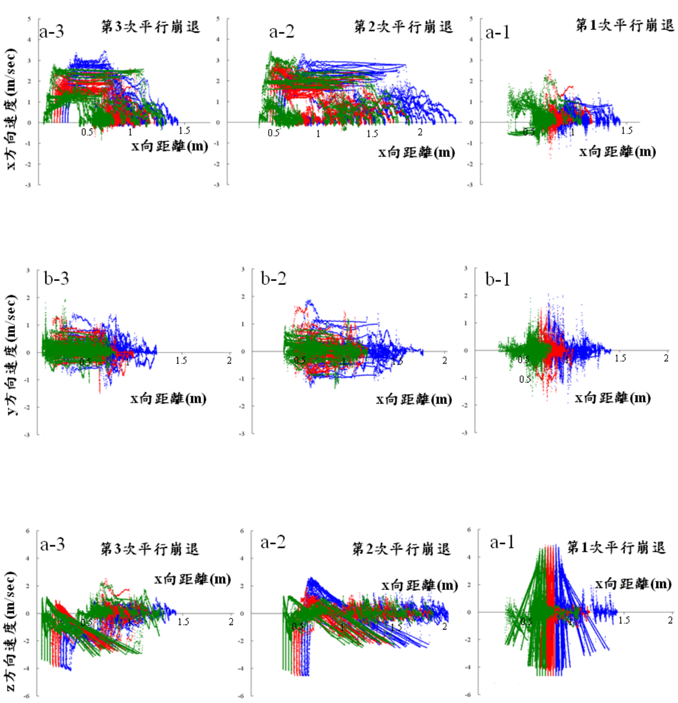


(d) 堆積



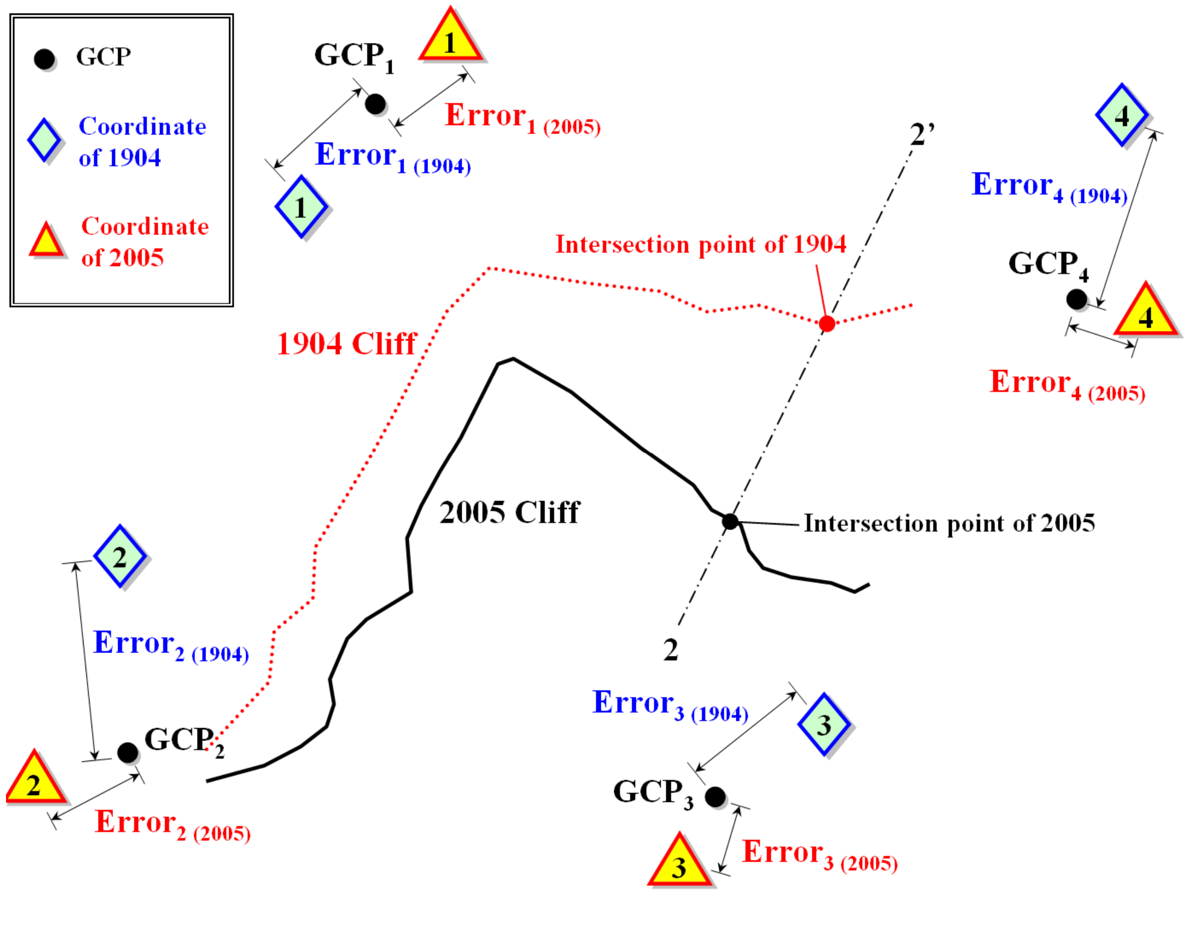


45度 地 3 度 圖

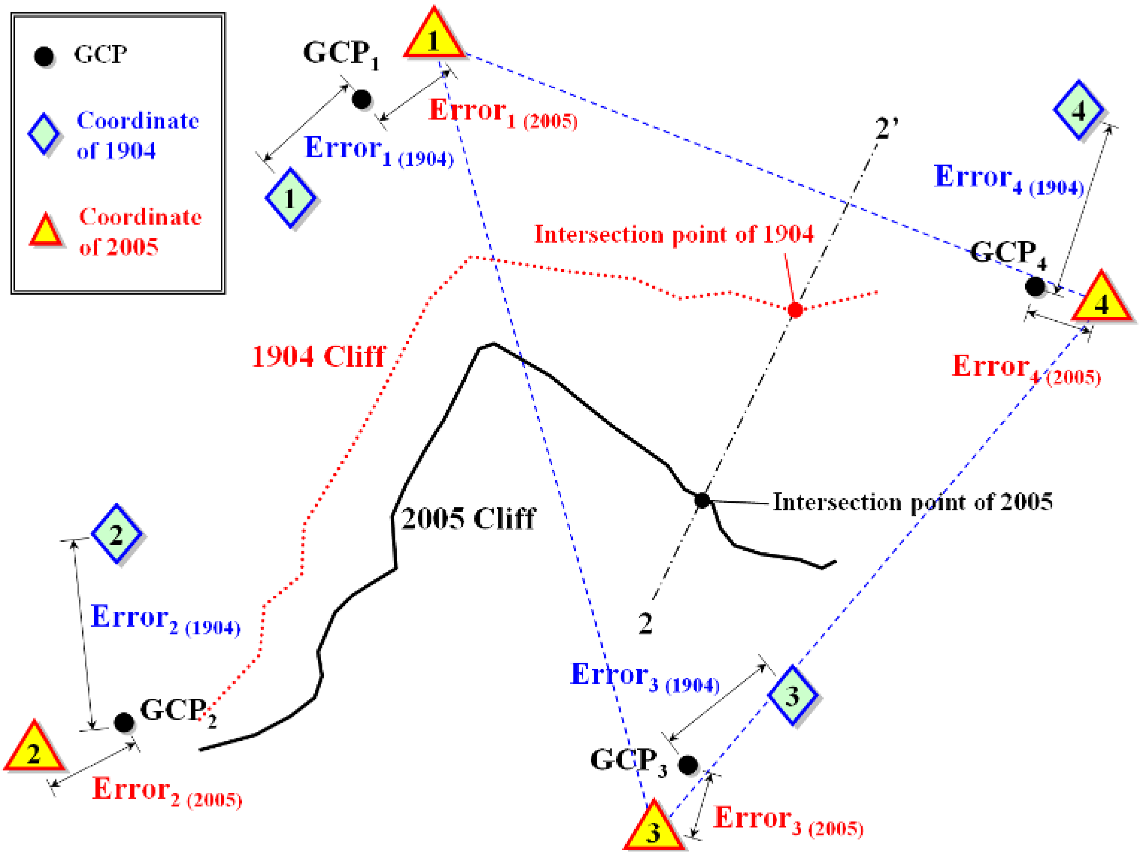


Geomorphologic analysis

(a)



(b)



GCP
Coordinate of 1904
Coordinate of 2005
GCP1
Error1 (2005)
Error1 (1904)
2'
Error4 (1904)
Intersection point of 1904
GCP4
1904 Cliff
Error4 (2005)
Intersection point of 2005
2005 Cliff
Error2 (1904)
2
Error3 (1904)
GCP2
GCP3
Error2 (2005)
Error3 (2005)