極端環境下之山崩防災創新技術研究：

*From **Numerical Modelling** to AI-Integrated Hands-on **Experiments***

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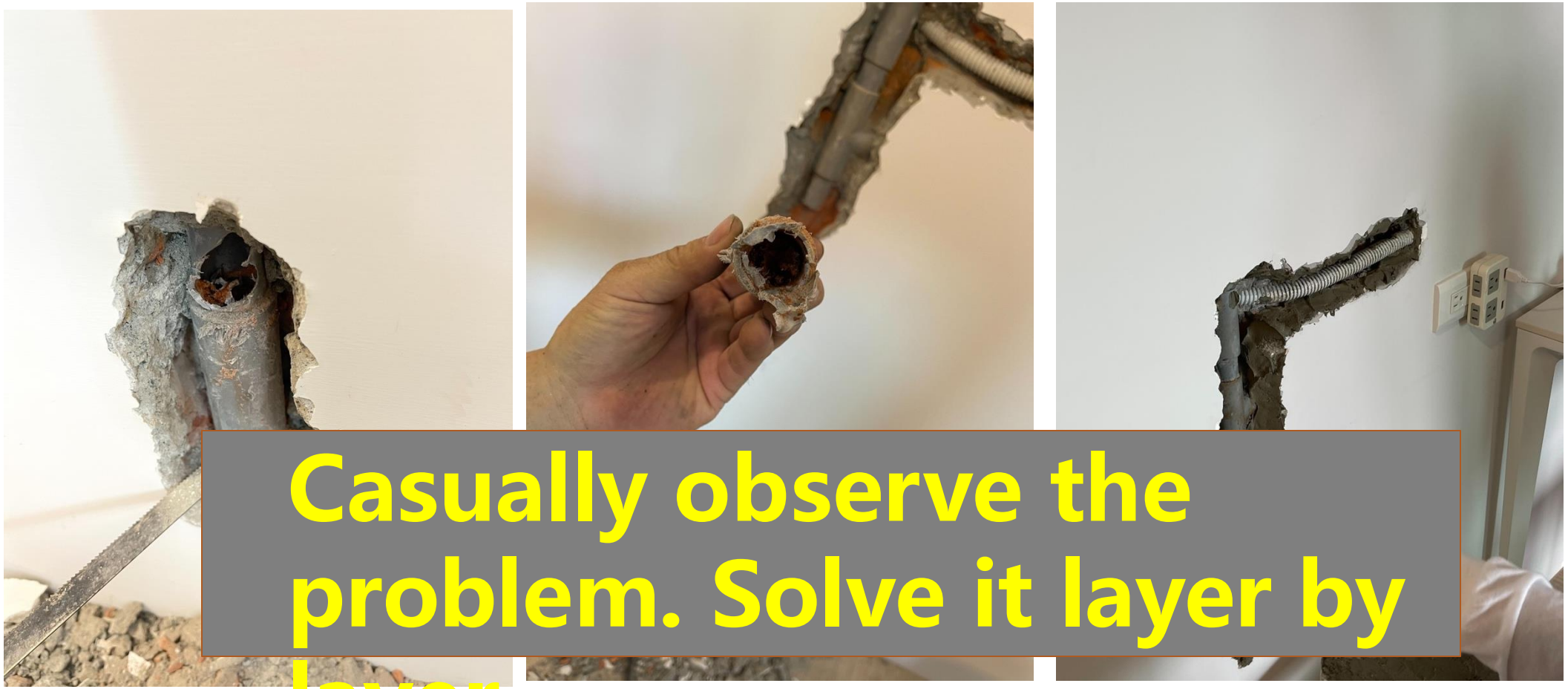
- 成大國際處 國際化組組長
- 荷商 ASML 資深研發工程師

其它著作：《自己的力學》、《先降噪，再聚焦》

Under the guidance of common sense and **casual observation**, I discovered weaknesses in traditional procedures and attempted to minimize them.

Sometimes I failed, but often I succeeded.

The air conditioner drain hole is clogged... What should I do?



Casually observe the problem. Solve it layer by layer.

Acknowledgement:

Jason, Soheil, Chih-Hsian, Cheng-Han, Huei-Sian & Chia-Ming (many others from the Smart GeoEngineering Lab and friends)

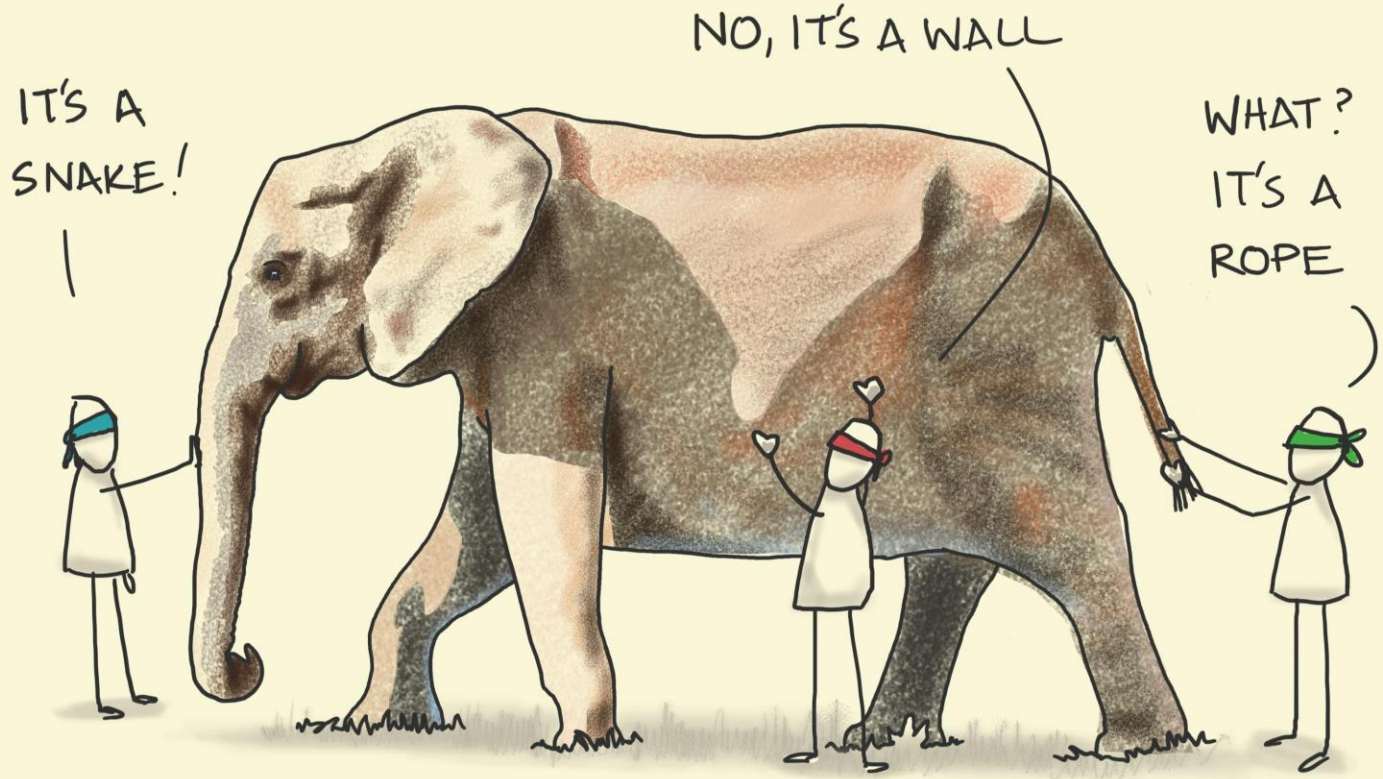
Extended appreciations:

- *National Research Institute for Earth Science and Disaster Resilience of Japan; Geospatial Information Authority of Japan; Geographical Survey Institute of Japan; Ministry of Home Affairs, Japan.*

國立成功大學
National Cheng Kung University

THE BLIND AND THE ELEPHANT

OUR OWN EXPERIENCE IS RARELY THE WHOLE TRUTH



sketchplanations

Outline: 1st Part in 3 Sections

One
Introduction & Motivation

Two
Novelty of FEM-DEM

Three
Application & Results

WHAT I CAN DO TO HELP
UNDERSTAND LANDSLIDES

THEME OF THE
FEM-DEM FRAMEWORK**?**

PROGRESSIVE MODELING OF
LANDSLIDES

Outline: 2nd Part in 2 Sections

Four

Coupled Eularian-Lagrandian (CEL)

ALTERNATIVE METHOD

FOR SIMULATING THE RUNOUT

WHY & SET UP

Five

Validations & Results

VALIDATING AGAINST

EXPERIMENTAL RESULTS

Beyond simulations

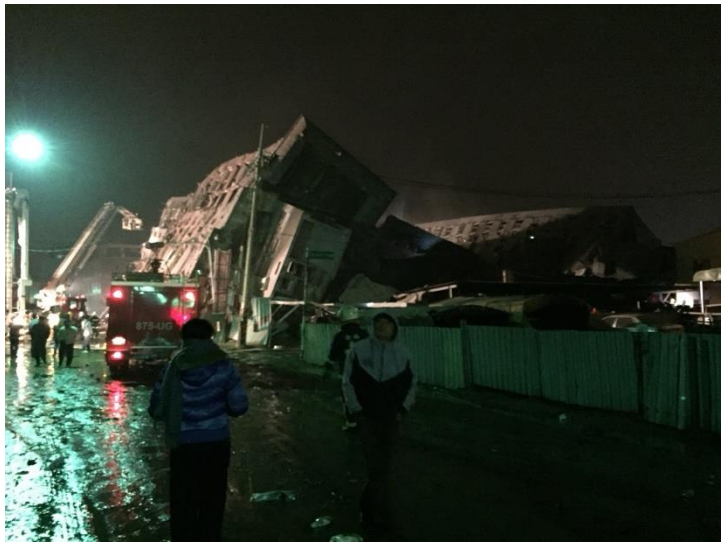
AI

Must-know Elements

LIMITATIONS & APPLICATIONS

Background Stories

- Sep 2015: Started my career at the NCKU
- Feb 2016:



COLLAPSE OF A LARGE RESIDENTIAL BUILDING IN TAINAN, CLAIMED 115 LIVES (2.6.2016)

GEER

BECAUSE OF THIS EVENT, I WAS INVITED TO GIVE A TALK ON 3.21.2016

(PHOTO NCREE)

Aso-Bridge coseismic landslide (4.14.2016)

One

Introduction & Motivation

WHAT I CAN DO TO HELP

UNDERSTAND LANDSLIDES

事故現場空拍顯示泥岩崩塌狀況。高大災害防救科技中心提供

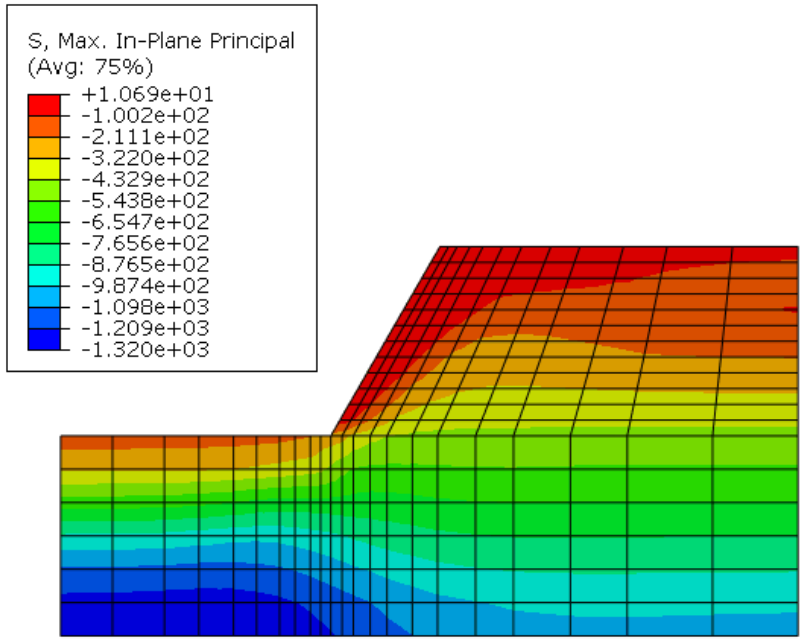
圖片1 / 3

Yanchao rainfall induced landslide (9.28.2016)

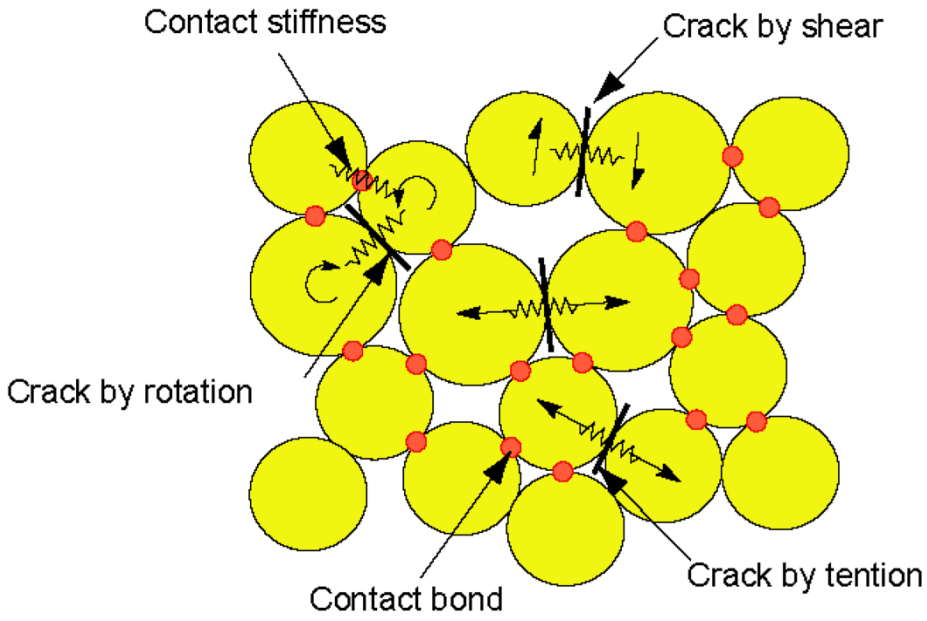
Introduction & Motivation

- Landslides have caused major damages worldwide; *likely* become *the new normal* due to climate change.
- Studies on landslides are *typically forensic in nature,* only focusing on the incipient and failure mechanism (typically by FEA and DEA).
- We see a gap between failure mechanism and kinematic runout process, i.e. connecting *small deformation to large distance sliding*.

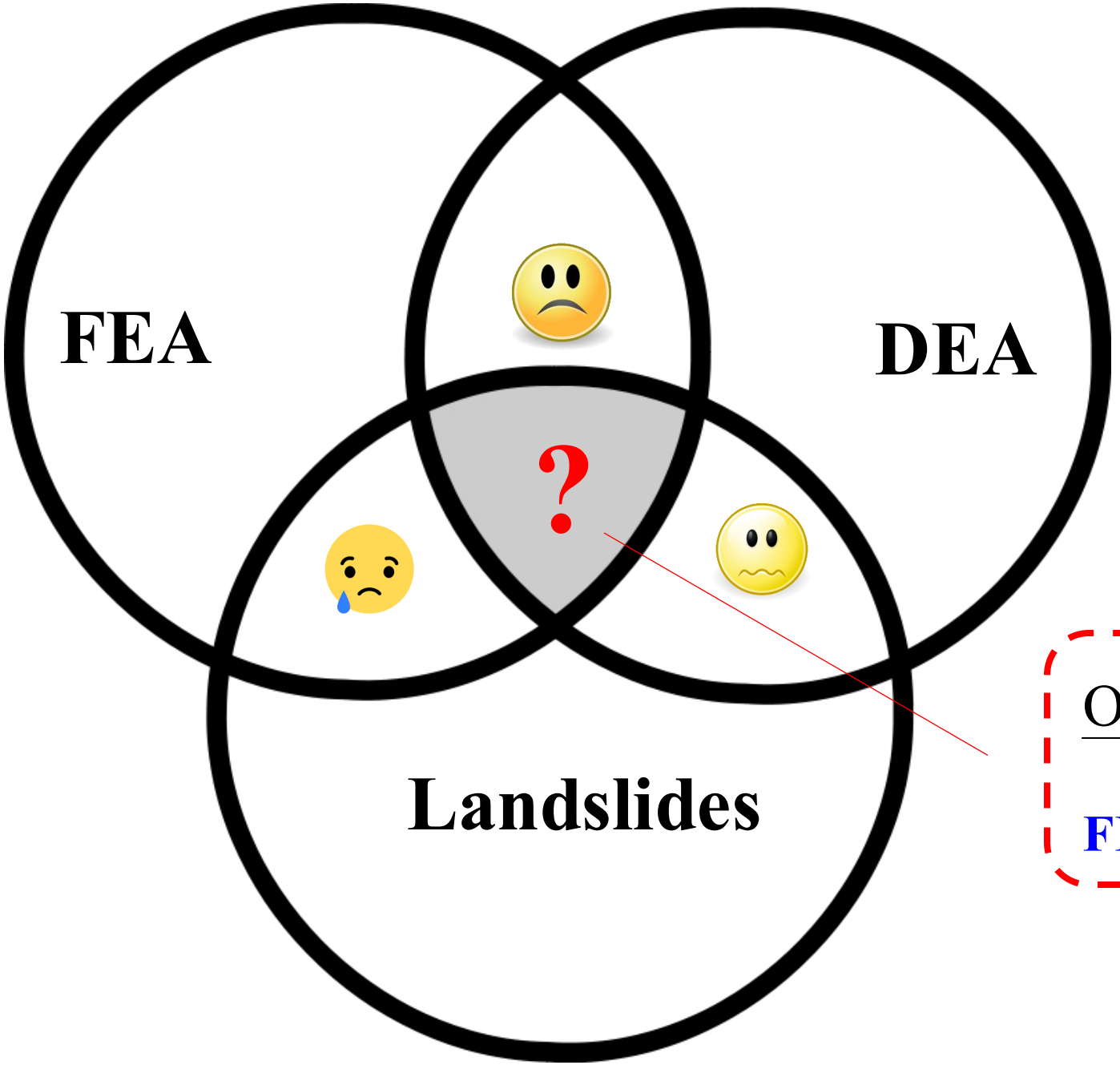
- **Finite element analysis (FEA) is an effective approach** for studying the onset of incipient failure of earthquake-induced landslides, including the sliding surface, initiation time, velocity.
- **Difficulties in modeling the postfailure runout behavior of landslides;** large displacements in the postfailure regime may **distort the element and introduce numerical inaccuracies**.



- Meshless approaches such as discrete element analysis (DEA) may better capture the **kinematic behavior of runout post-failure**
- DEA treats geomaterials as **discontinuous bodies**, making it suitable for simulating the rolling, translation, and potentially disintegrative behavior of sliding mass following failure



Contact Bond Model



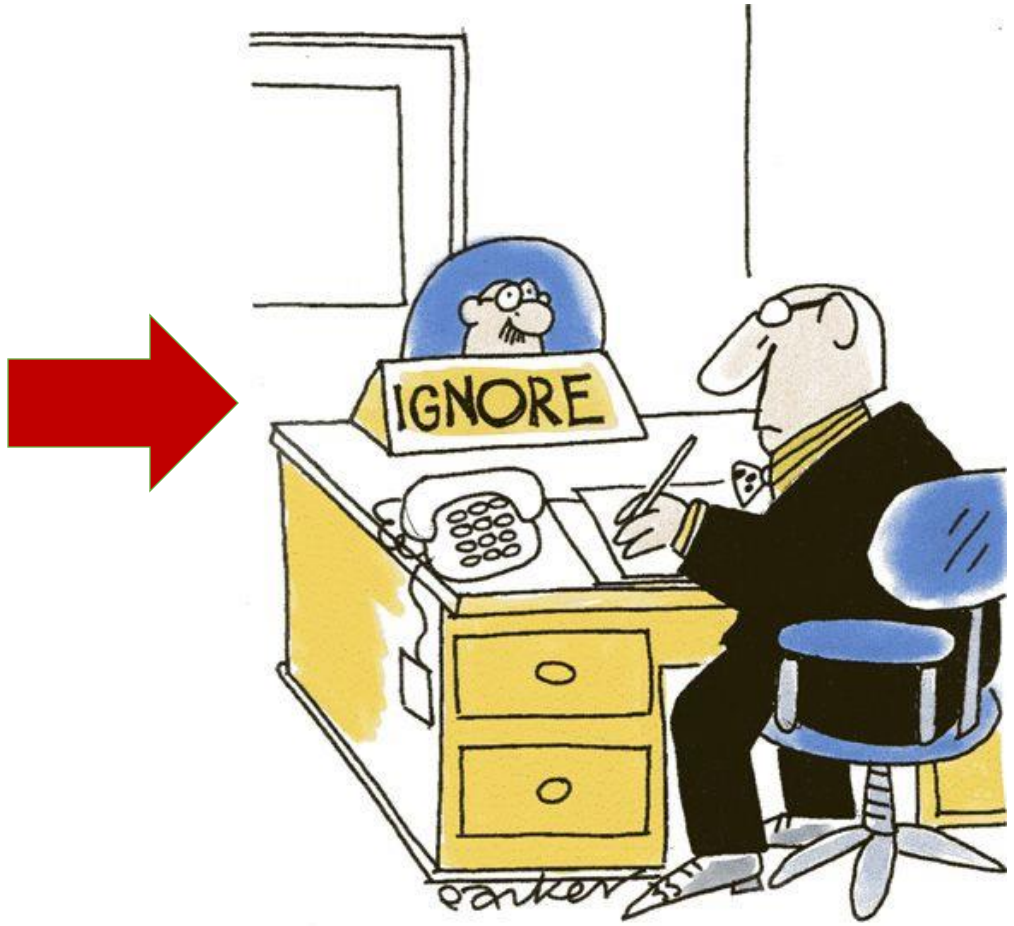
Discussions

One of a potential *Solution*:

FEM-DEM framework

- While **DEA** is widely recognized as a robust numerical tool for modeling landslide runout, its incipient failure geometry typically **must be determined *a priori***. Furthermore, at initiation the velocity of the failing mass **is assumed to be 0 m/s**

- In the past decade, the coseismic landsliding has been examined through numerical simulations that **often ignore vertical seismic acceleration (VSA) for simplicity**, although it may have significant impacts on landslide deformation.



Rational seismic analyses should consider both HSA and VSA

Ling et al. (2014)

VSA plays a key role when ratio of vertical to the horizontal accelerations is high

Yin (2014)

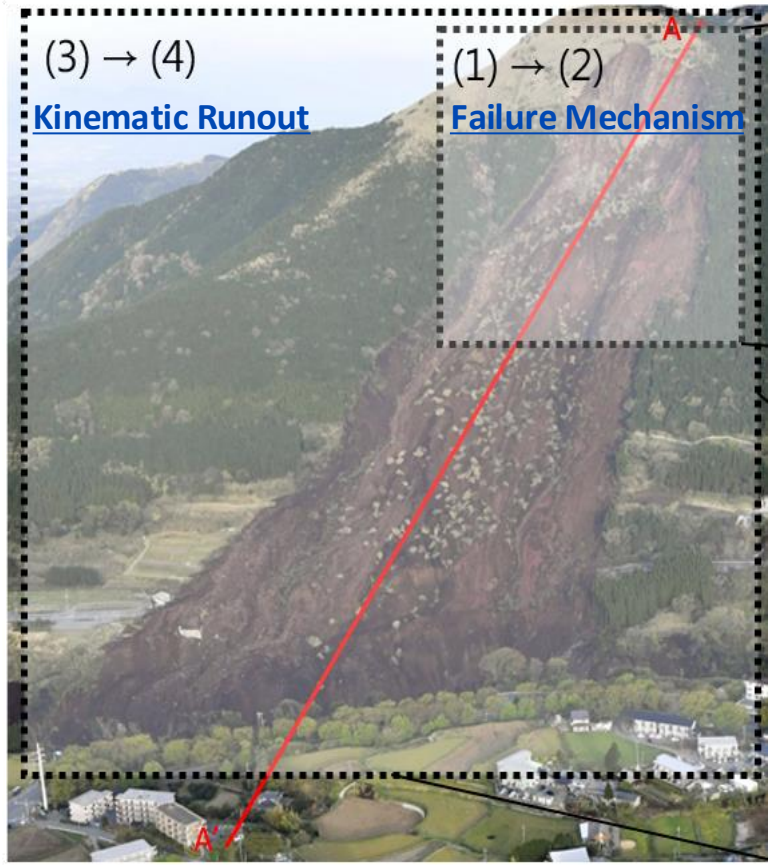
VSA has a significant influence on the initiation mechanism

Zhang et al. (2015)

Notice that: the connection between failure and runout can be very damaging to recovery efforts and disaster response.

Predicting the affected zones
Implementing countermeasures

Progressive behavior of landslides include: failure mechanism and runout behavior.



e.g. Aso-Bridge coseismic landslide

Finite element method (FEM)

Failure Mechanism:

1. Small deformation
2. Pre-failure condition

Discrete element method (DEM)

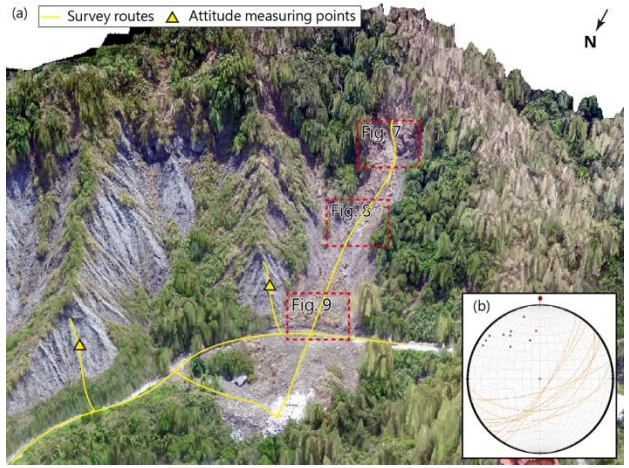
Kinematic Runout:

3. Large distance sliding
4. Sliding process

Forensic studies ↘ ↙ *Ignore initial condition*

Can be connected

Thereby, we propose the FEM-DEM procedure connecting the gap.



Field investigation of Yanchao rainfall-induced landslide (2016)

Two

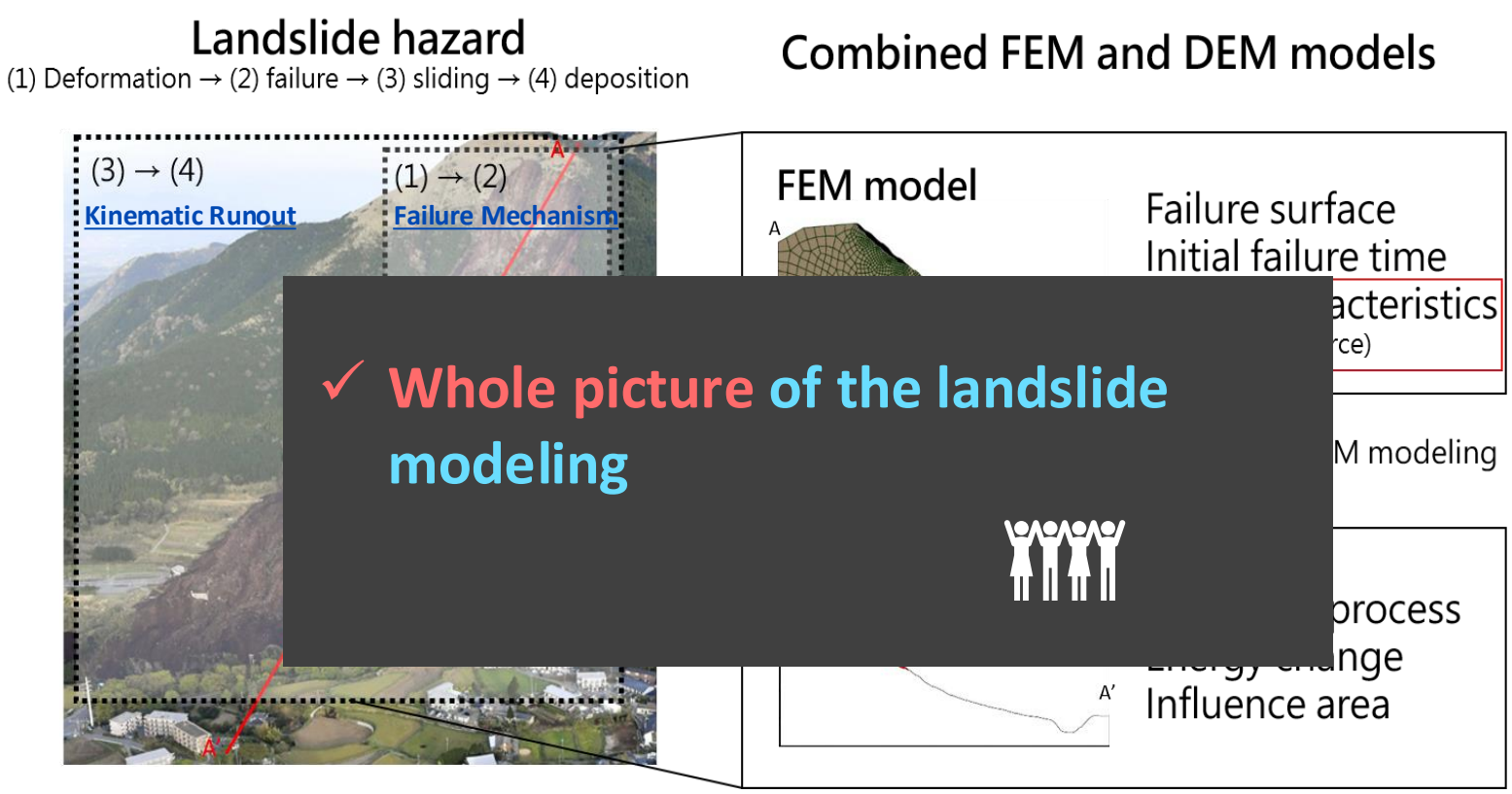
Novelty of FEM-DEM

WHAT IS THE THEME OF THE

FEM-DEM FRAMEWORK**?**

Experimental studies for coseismic behavior @ncku

Concept of the FEM-DEM framework:



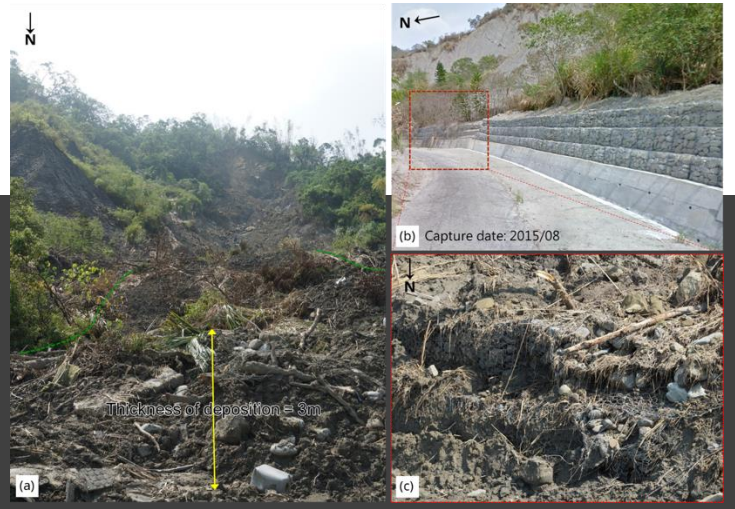
Slient Feature:

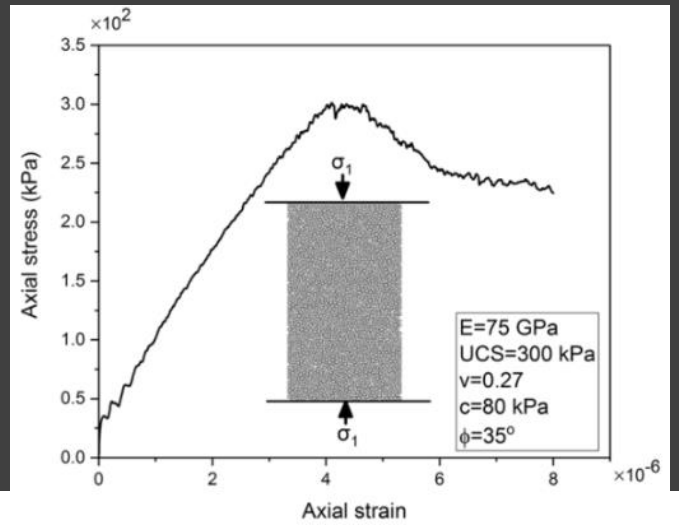
Geohazards containing pre- & post- failure behaviors, involving small and large deformations.

Prerequisite (Emphasize)

- Insights from field investigation, monitoring, and physical testing are important to ensure a realistic application and interpretation.

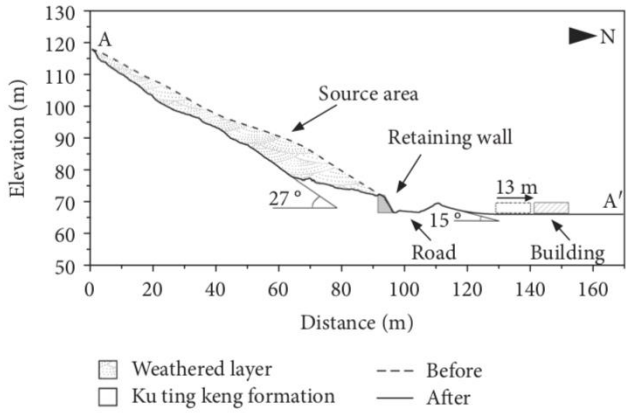
- Be very familiar with the numerical themes, the material models, calibrations of macro- and *micro- properties*, boundary conditions, etc.





Prerequisite (procedurals)

- Sampling frequency of the earthquake signals should match the calculation steps in the explicit formulation in the algorithm.
- To minimize the calculation time (computation power), a proper simplification on the input of the seismic signals should be considered.



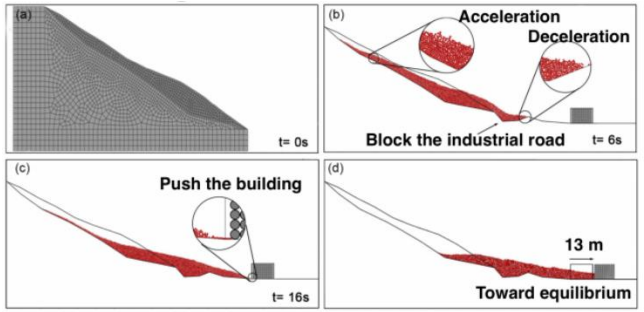
Digital elevation model of the Yanchao landslide (2016)

Three

Practical Application

PROGRESSIVE MODELING OF TWO

LANDSLIDES



Mechanism of the rainfall-induced Yanchao landslide (2016)

1st Case Facts: the Aso-Bridge Coseismic Landslide

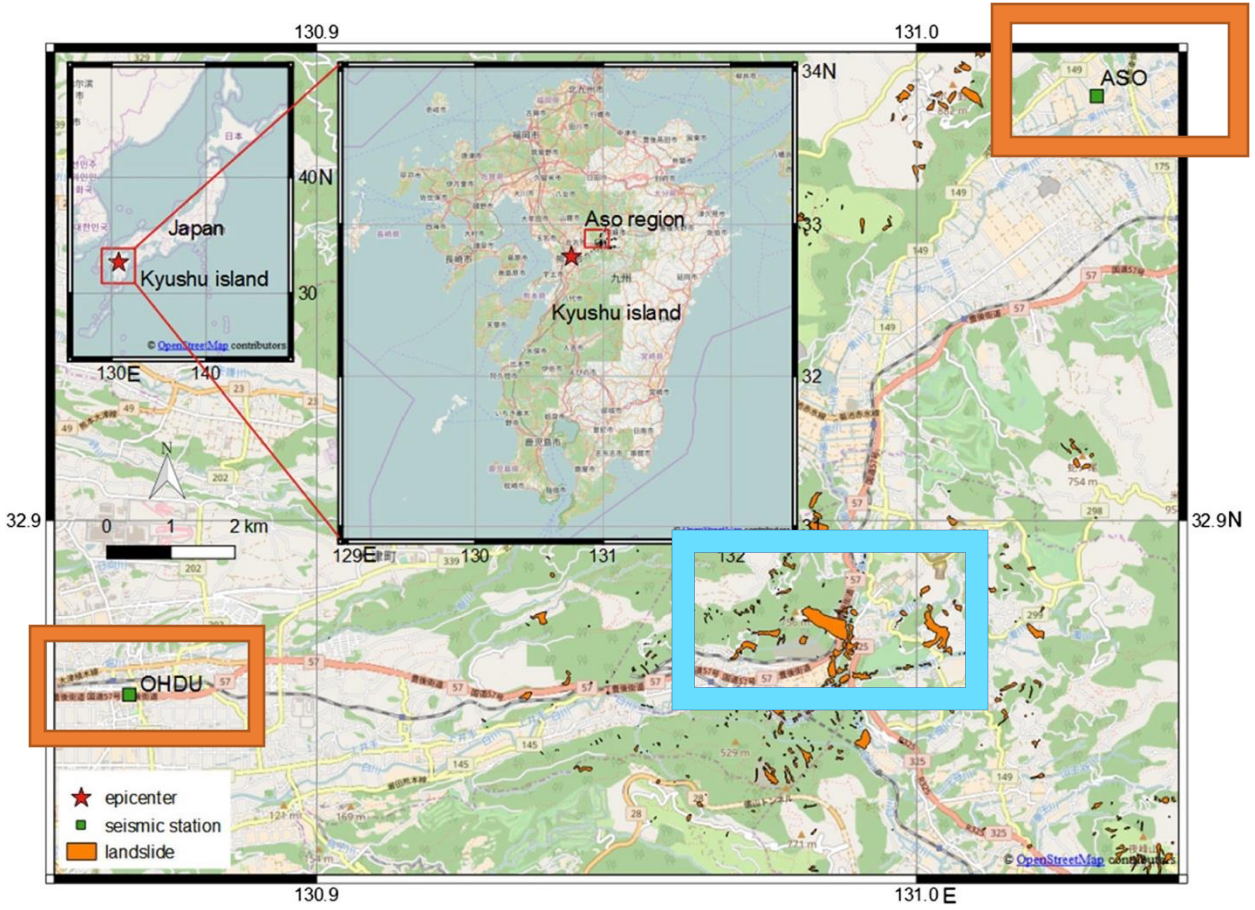
Aso-Bridge coseismic landslide (2016)

The Aso-Bridge landslide, located west of the caldera of the nearby **Aso Volcano**, was triggered by the 2016 Kumamoto earthquake.

This is a recent well-known large-scale earthquake-induced.

Most of the required information are available.

Facts: the Aso-Bridge Coseismic Landslide

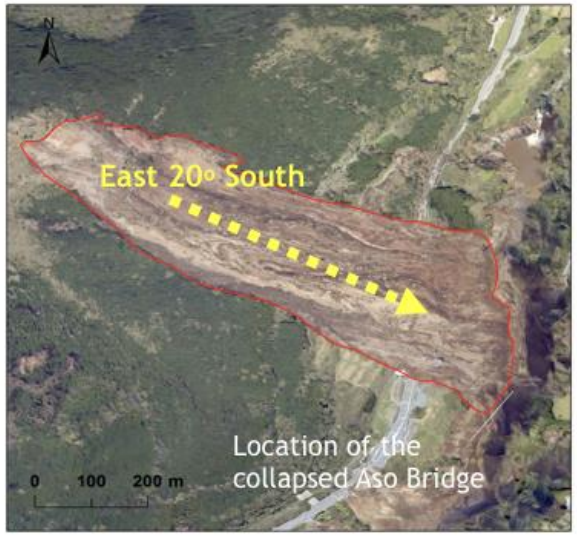


One of the biggest landslides triggered by the earthquake.

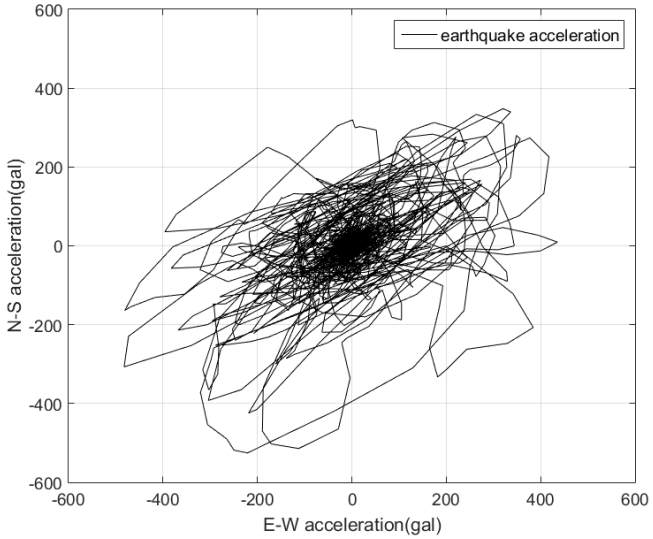
The estimated area of the Aso-Bridge landslide is about 180,000 m^2 (18 ha).

Classified as a *large-scale landslide* because the affected area exceeded 10 ha.

Facts: Foreshock & Main-shock



Seismic Motions in N-S and E-W directions



foreshock earthquake | main-shock | after-shocks

magnitude of 6.2

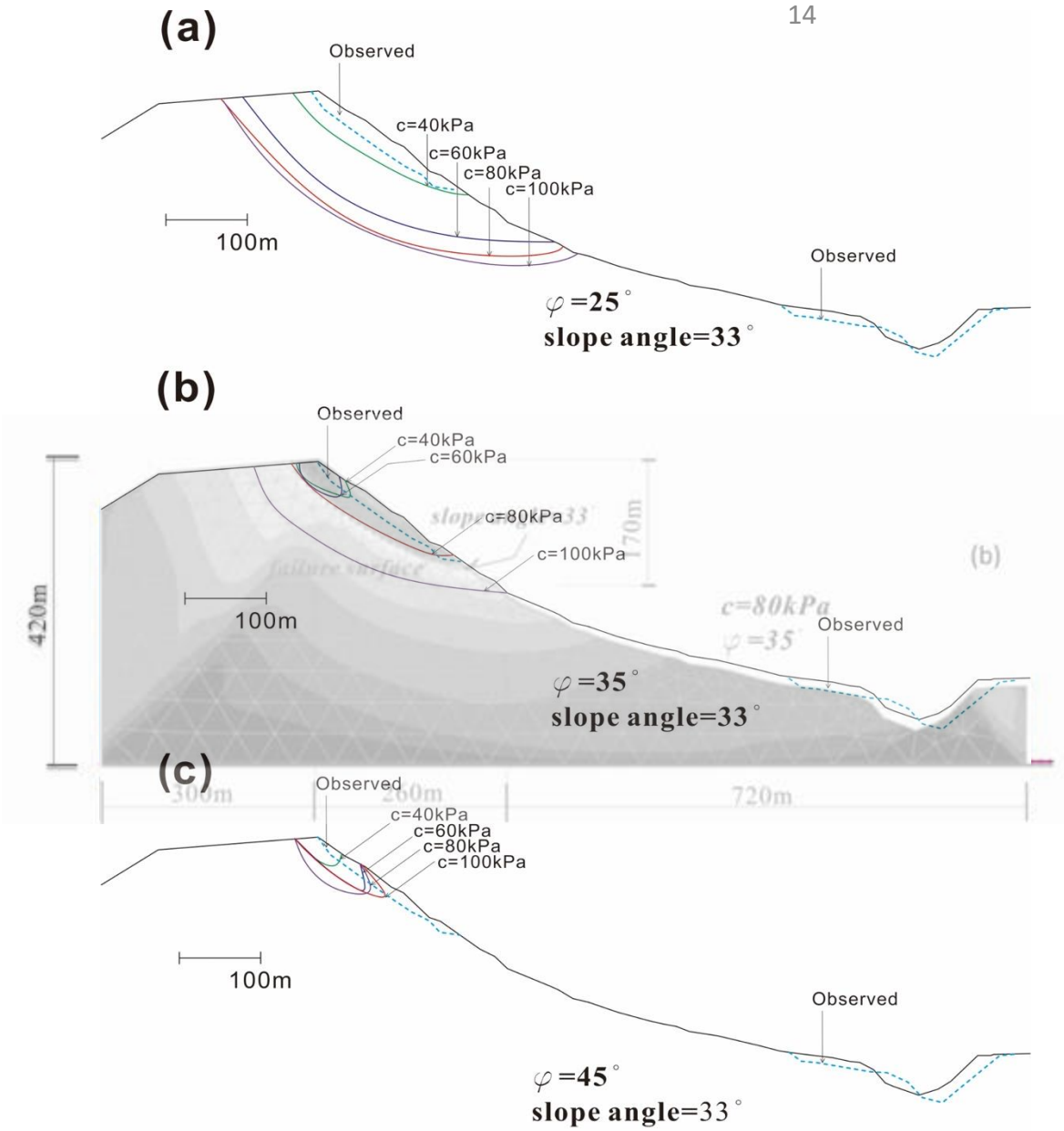
2016/4/14
12:26 (UTC)

magnitude of 7.3

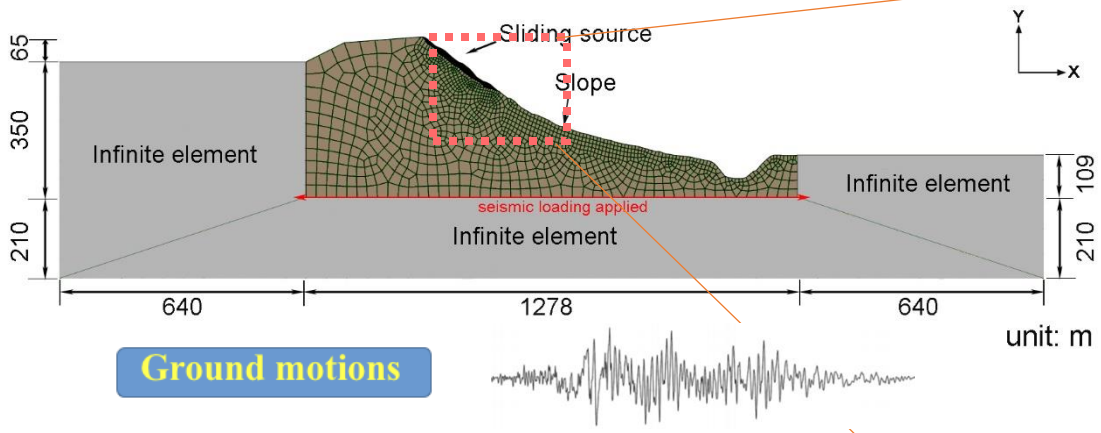
2016/4/15
16:25 (UTC)

FEM: Sensitivity Analyses

- The FEM was able to estimate a satisfactory failure surface.
- Inverse relationship b/w the internal frictions and failure surfaces (*Pyroclastics in Aso*).
- **Failure occurred immediately at the ridge** when the main shock hit (revealed by a dynamic analysis).



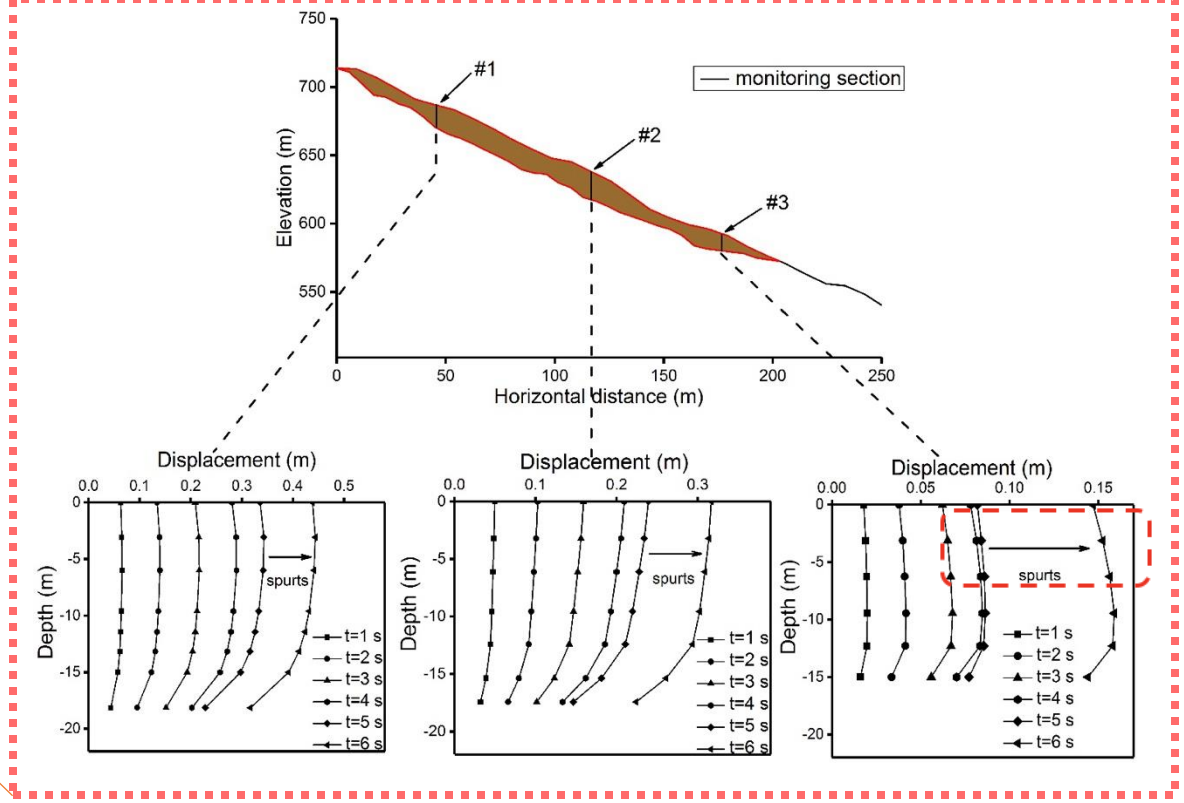
1. Small Deformation (FEM)



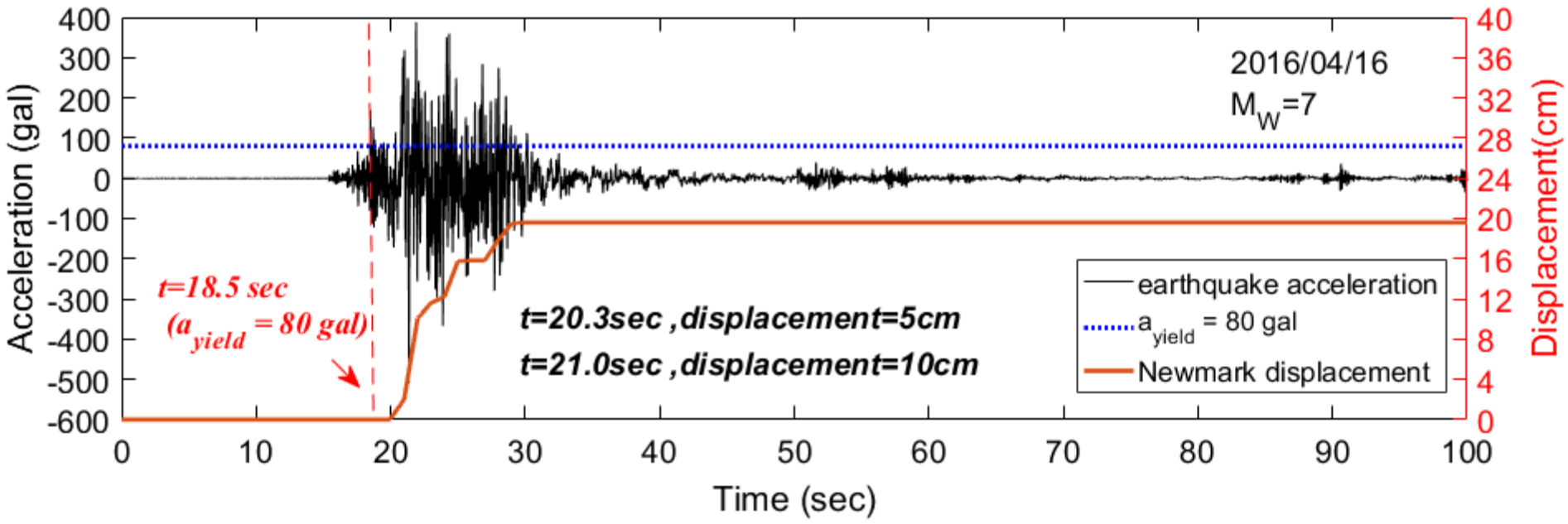
Reveal (not limited to):

- *Failure mechanism*
- *Define initiation time (5.6 s after main earthquake shock)*
- *Initiation sliding velocity (17 cm/s)*

Results of Deformation vs. Time

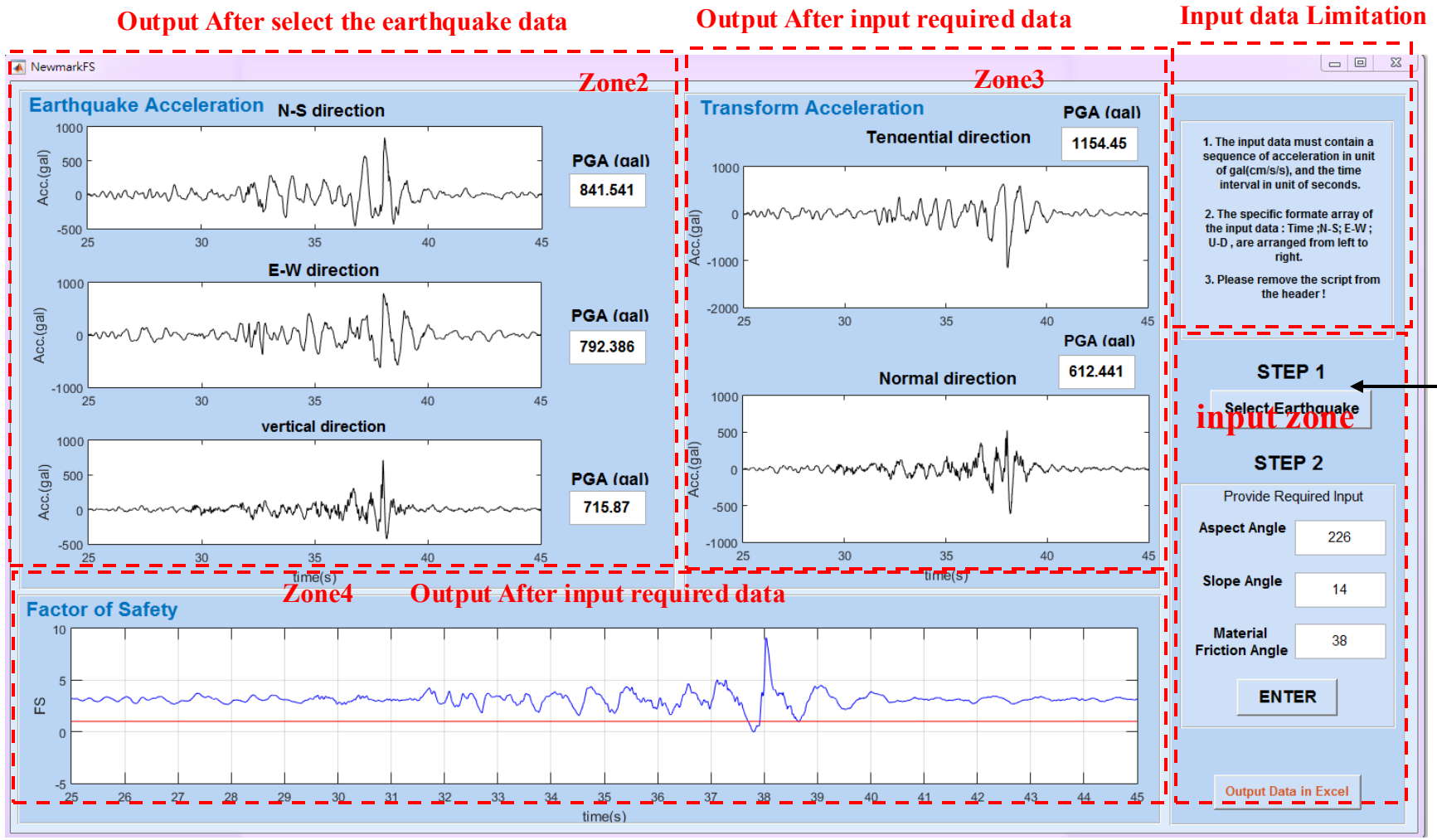


Initiation time was validated by Newmark's method



- Suggesting that the landslide might have been initiated when **displacement reached 5 - 10 cm**

Additionally: a GUI App was also created to help estimating the Initiation time of landslides (coseismic)




```
#StationCode: CHY080
#InstrumentKind: A900A(T362002.263 )
#StartTime: 1999/09/20-17:47:02.000
#RecordLength(sec):   90.00
#SampleRate(Hz): 200
#AmplitudeUnit:  gal. DCoffset(corr)
#AmplitudeMAX. U:  715.870~ -426.886
#AmplitudeMAX. N:  841.541~ -463.192
#AmplitudeMAX. E:  792.386~ -627.789
#DataSequence: Time U(+); N(+); E(+)
#Data: 4F10.3
     0.000    -0.050    -0.109    -0.215
     0.005     0.010     0.131     0.024
     0.010     0.070    -0.109    -0.036
     0.015     0.010     0.071    -0.036
```

Importance of the Initiation time:

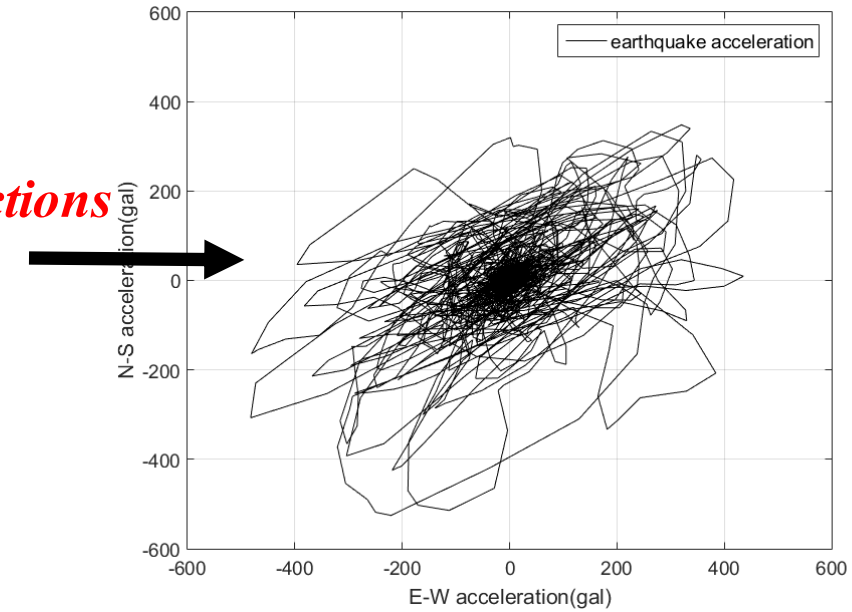
It is required to better understand the landslide mechanism.

Usually guessed in the past!

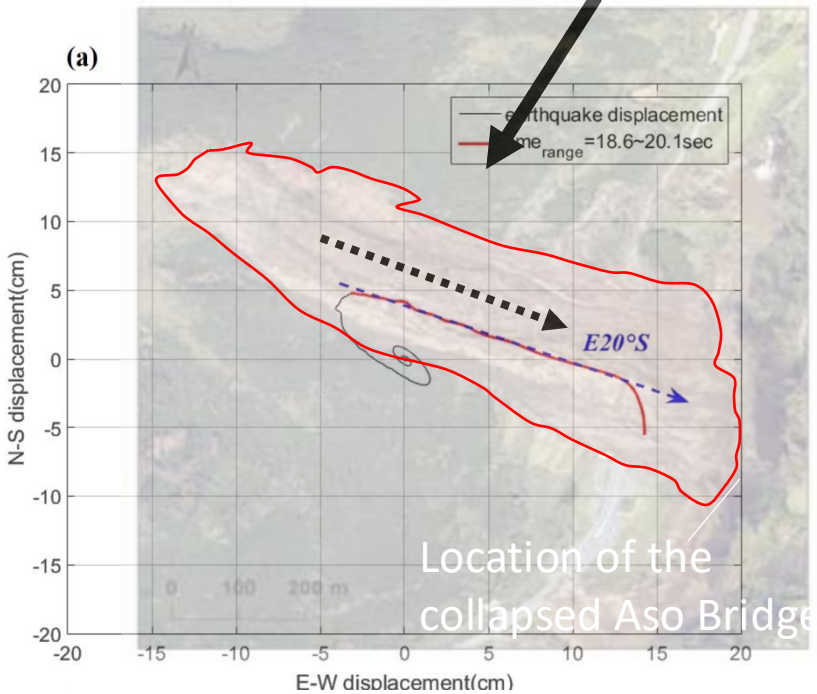
Also, initiation time was validated by apparent direction

Clear directional tendency matching the sliding direction at the similar time

lacking directions

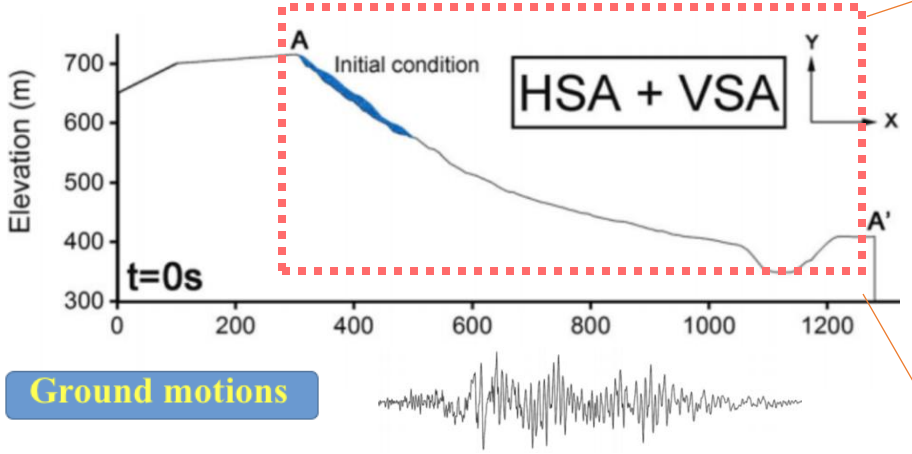


Seismic Accelerations (Kumamoto Earthquake)



Double Integration of the Seismic Accelerations

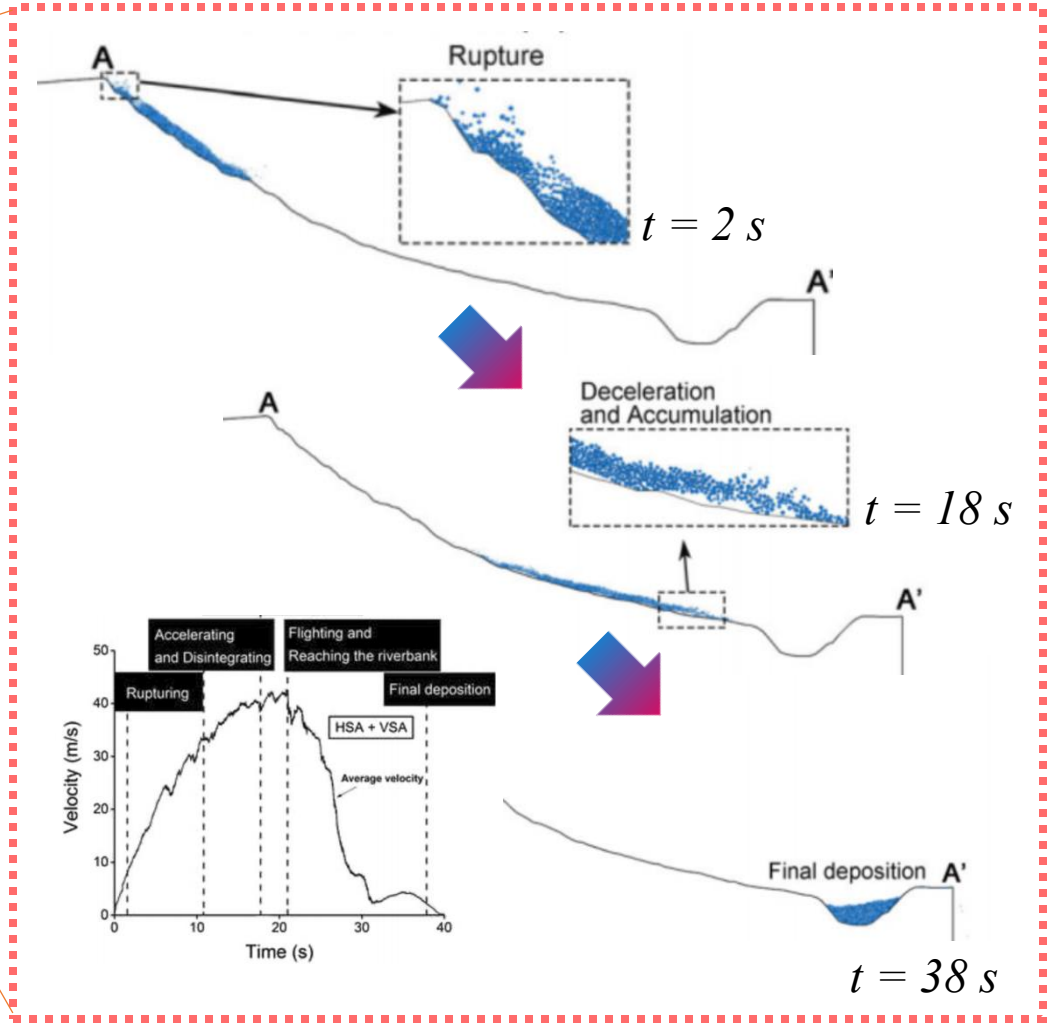
2. Large Distance Sliding (DEM)



Reveal (not limited to):

- *Process during the sliding*
- *Sliding ends within 38 s*
- *Affected area and impact forces*

Results of Kinematic Process

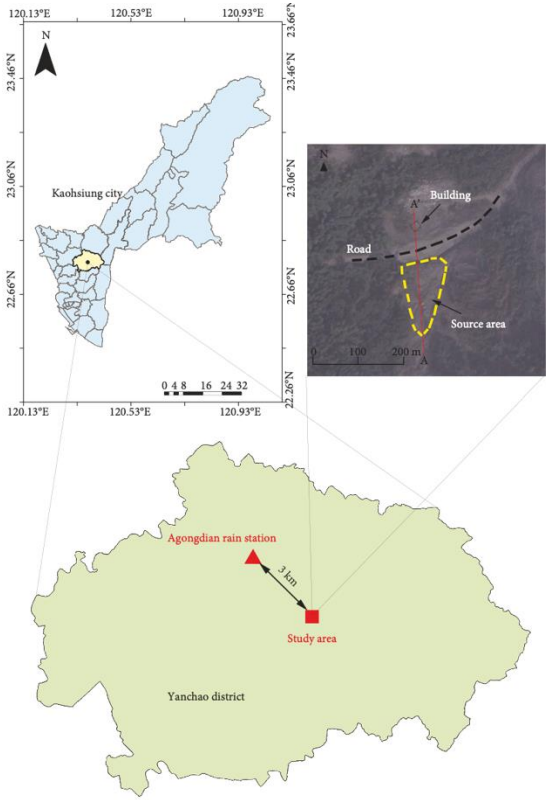


Addressing Vertical Seismic Acceleration (VSA)?

The initiation times for the two seismic input conditions **appeared identical**; however, a more accurate initiation time for the landslide could be observed if VSA was considered.

The result suggested that both **HSA and VSA should be considered** to ascertain the initiation time of coseismic landslides.

2nd Case *Facts: the Yanchao Rainfall-induced Landslide*

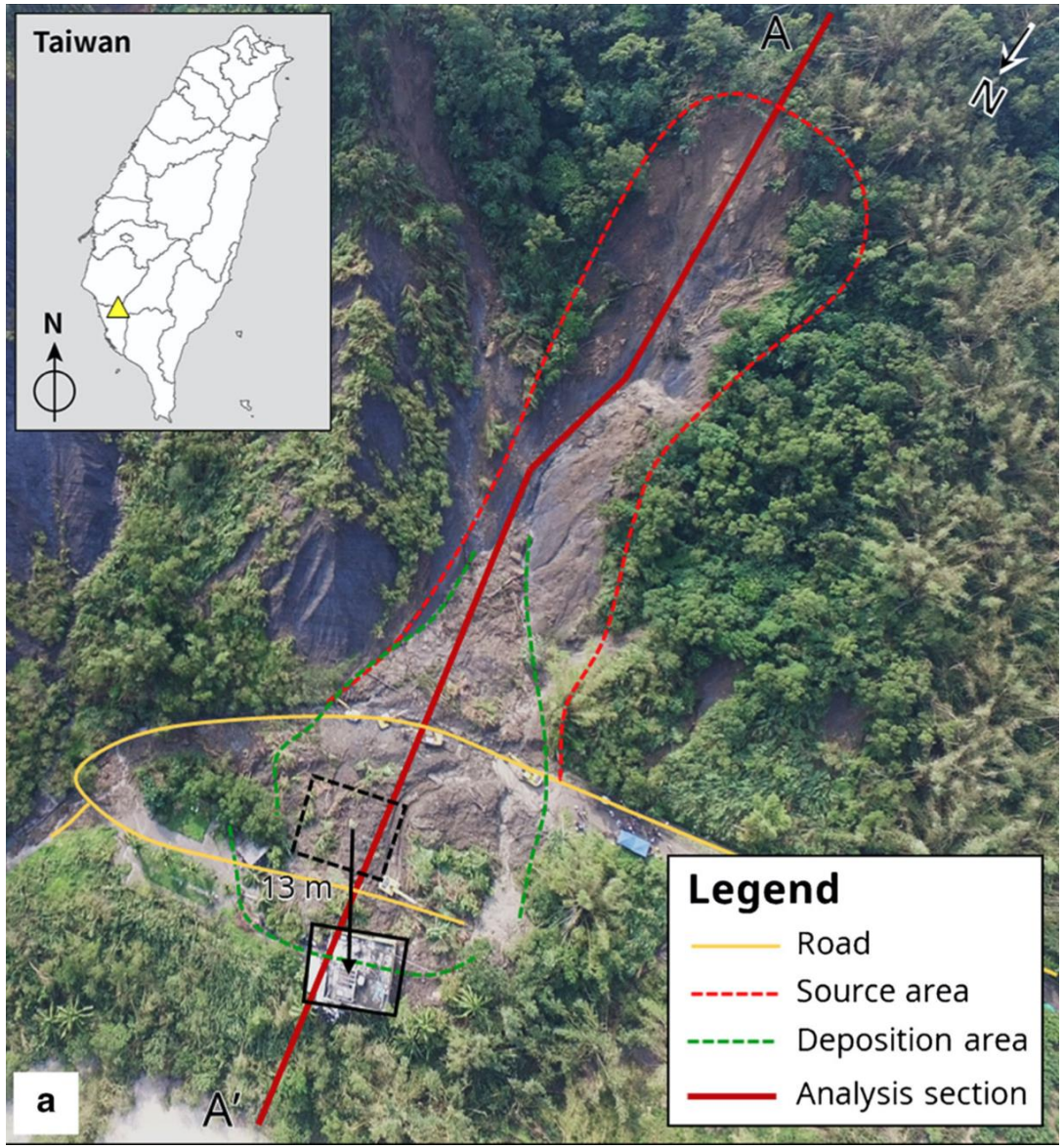


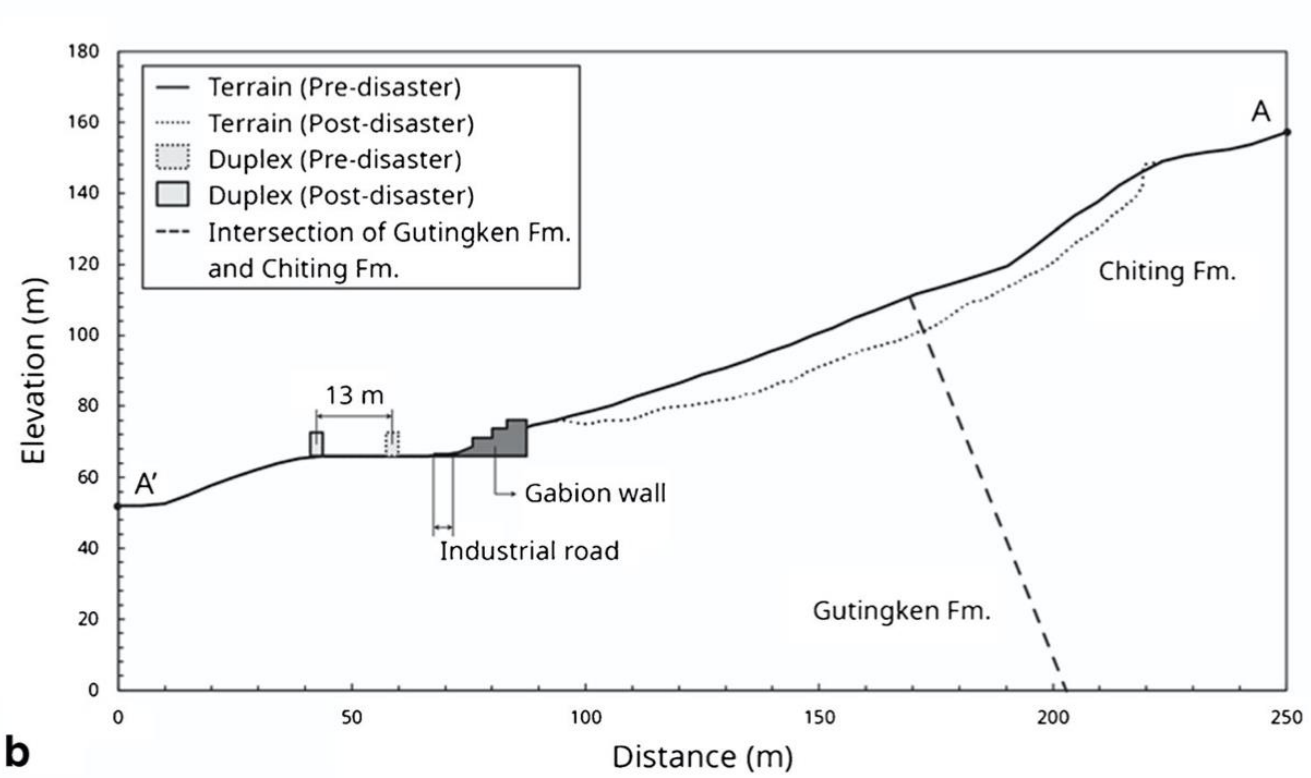
Yanchao rainfall-induced landslide (2016)

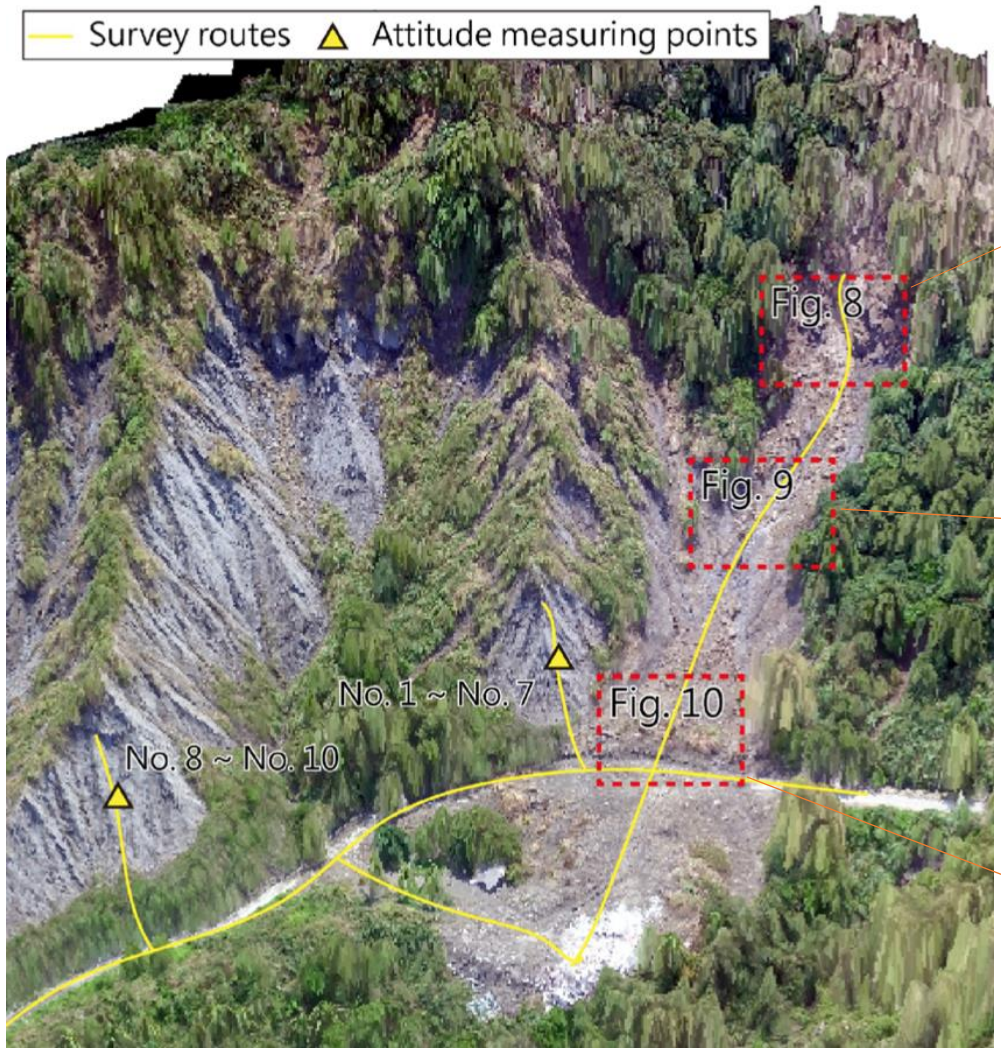
The Yanchao landslide occurred as a result of a "torrential" rain event brought by the typhoon Megi.

Very few landslides had been observed in the area. A newfound challenge in the mudstone area.

Understanding the interplay of rainfall in a mudstone landsliding would help reveal the prefailure mechanism.


Taiwan
N
A
N
13 m
A′
a
Legend
Road
Source area
Deposition area
Analysis section


Terrain (Pre-disaster)
Terrain (Post-disaster)
Duplex (Pre-disaster)
Duplex (Post-disaster)
Intersection of Gutingken Fm. and Chiting Fm.
Elevation (m)
Distance (m)
A
A′
13 m
Gabion wall
Industrial road
Chiting Fm.
Gutingken Fm.
b

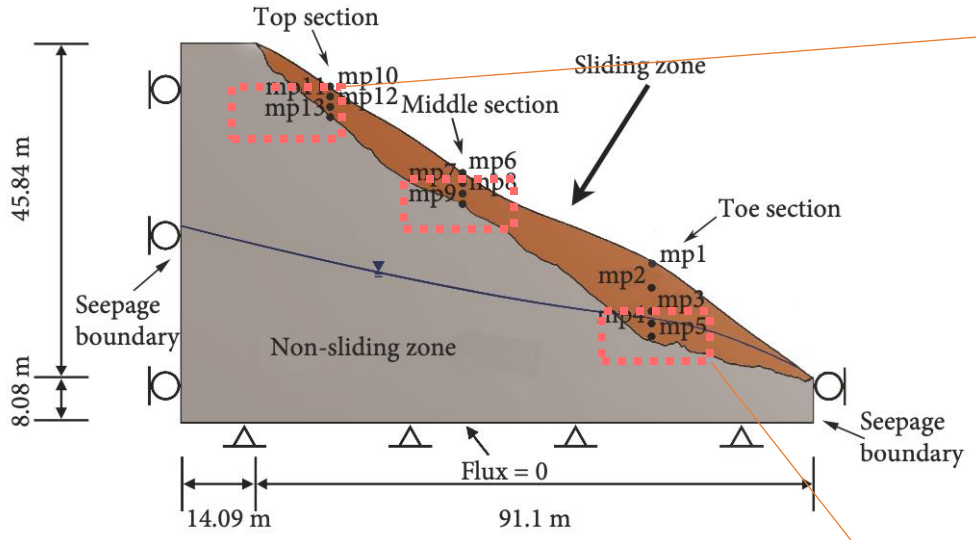

Survey routes
Attitude measuring points
Fig. 8
Fig. 9
Fig. 10
No. 1 ~ No. 7
No. 8 ~ No. 10

N
Pipe inlet

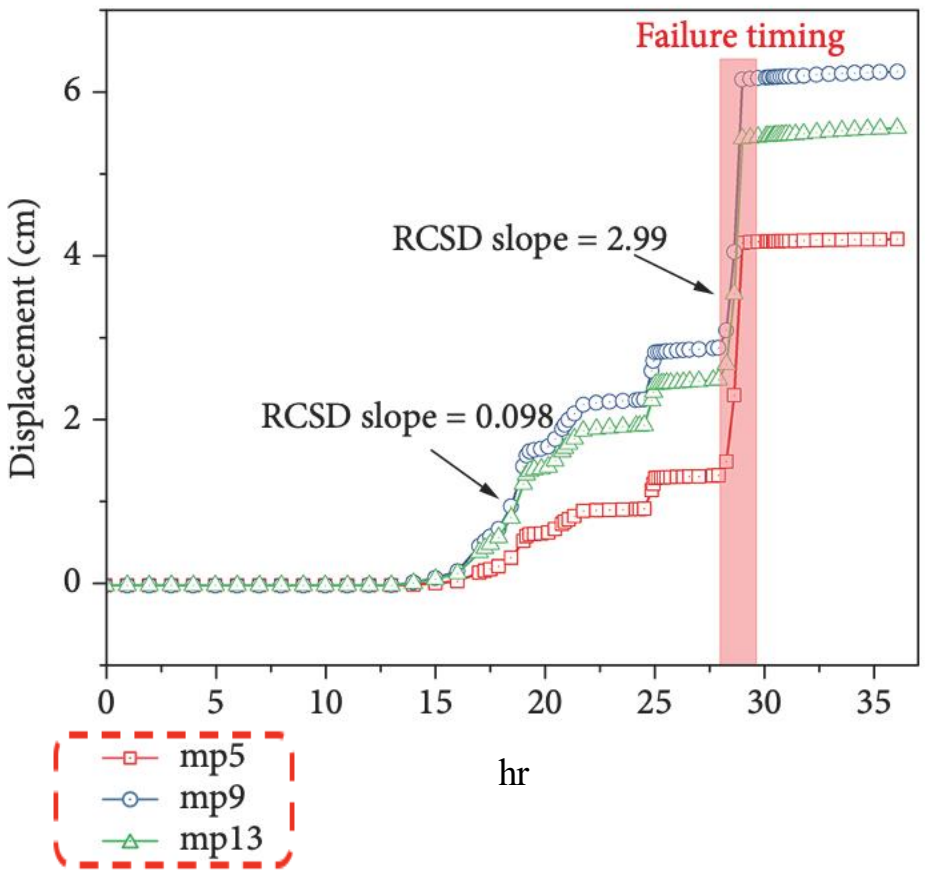
Pipe outlet

Thickness of deposition = 3m

1. Small Deformation (FEM)



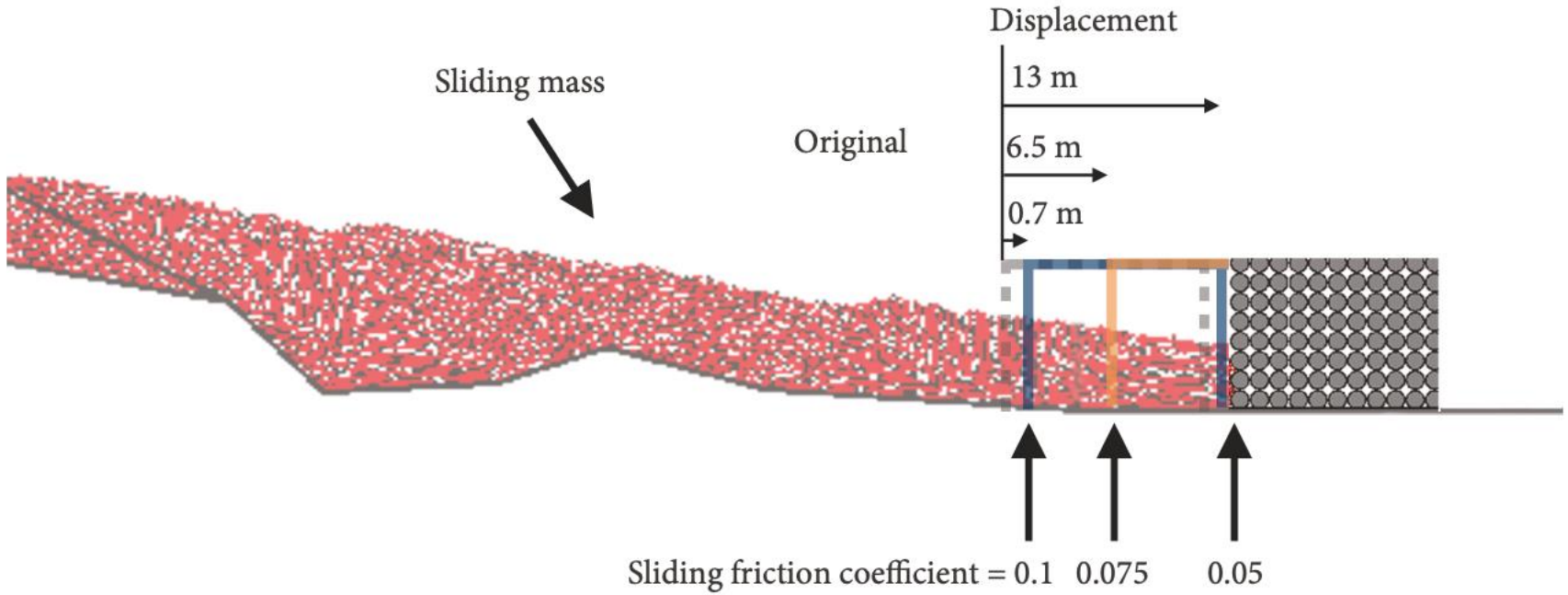
Results of Deformation vs. Time



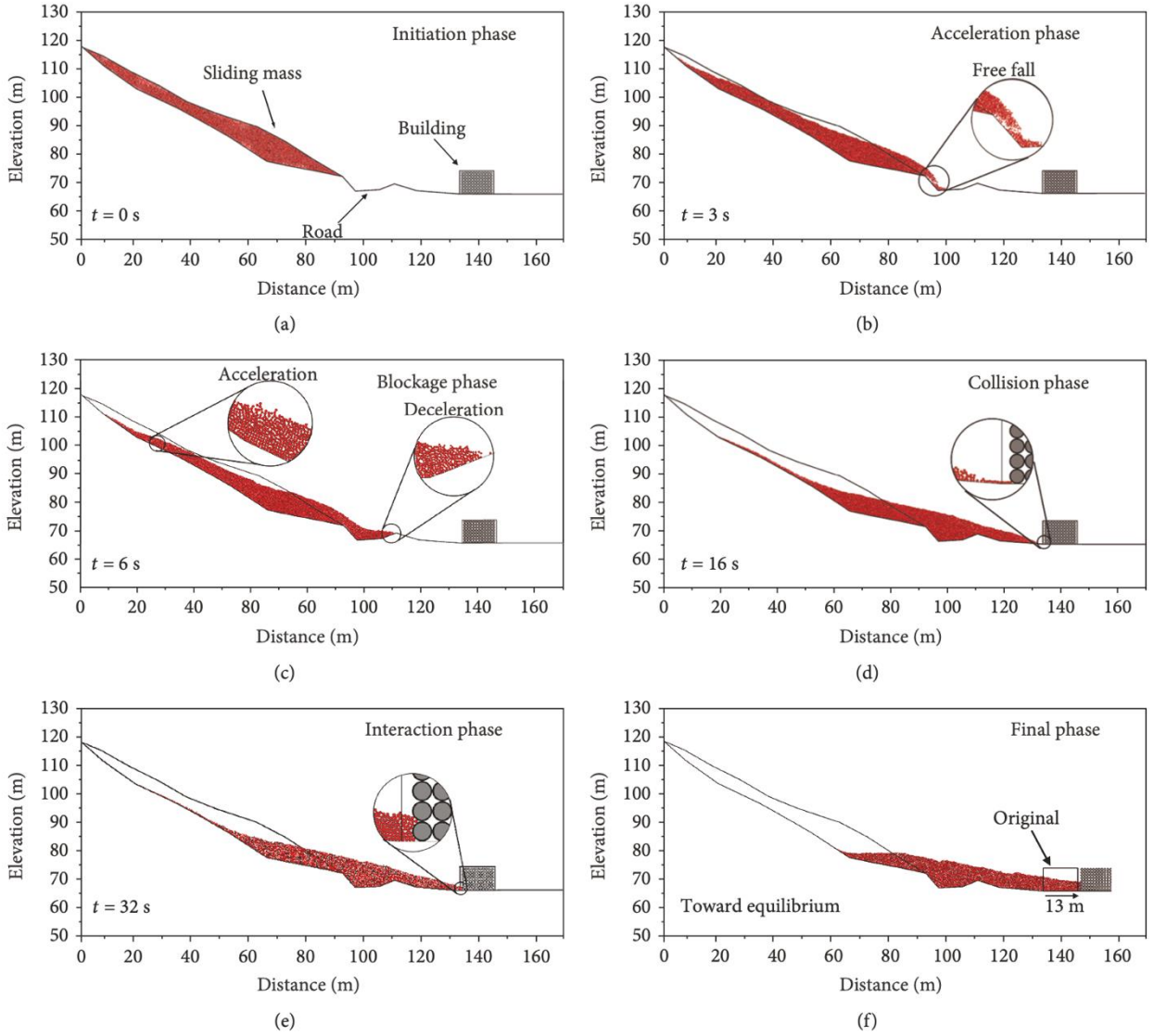
Reveal:

- *Failure mechanism*
- *Failure timing @28hr, by RCSD*
- *Initiation seepage force is 0.5 N*

A frictional rheology can be validated by the displaced building



Results of Kinematic Process



Phases:

a) Initiation; b) Acceleration; c) Blockage; d) Collision; e) Interaction; f) Final.

Recap of the First Part

1. Addressed: importance in connecting failure mechanism to runout process (*small deformation to large distance sliding*).

2. Highlighted: FEM-DEM framework, and emphasized its prerequisite.

3. Sliding behaviors are dominated by the terrain.

Four

Coupled Eularian-Lagrandian (CEL)

ALTERNATIVE METHOD

FOR SIMULATING THE RUNOUT

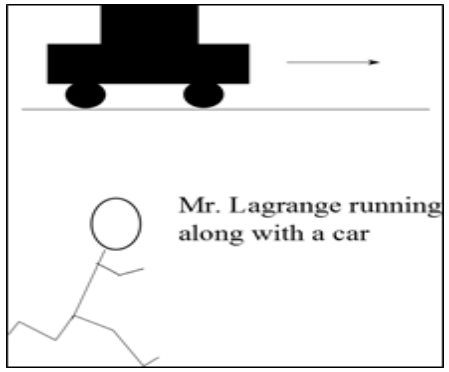
WHY?

Motivation to using the CEL method?

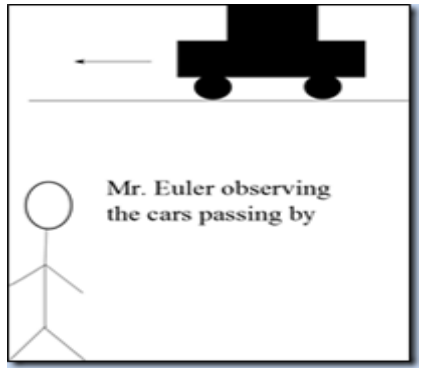
- Eliminating the calibration process of the micro-properties.
- Testing and expanding an alternative approach, replacing the DEM.
- Experimental results are readily available (sandbox and column collapse).

Brief overview of the Coupled Eularian-Lagrangian (CEL) method

Lagragian Step



Euler Step



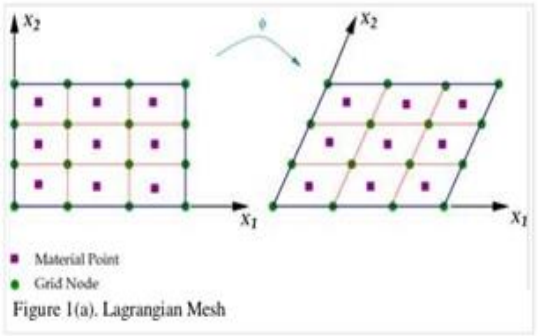


Figure 1(a). Lagrangian Mesh

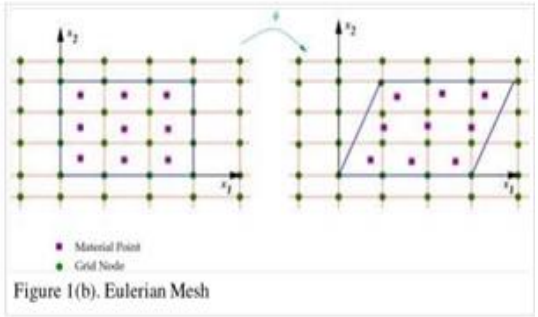
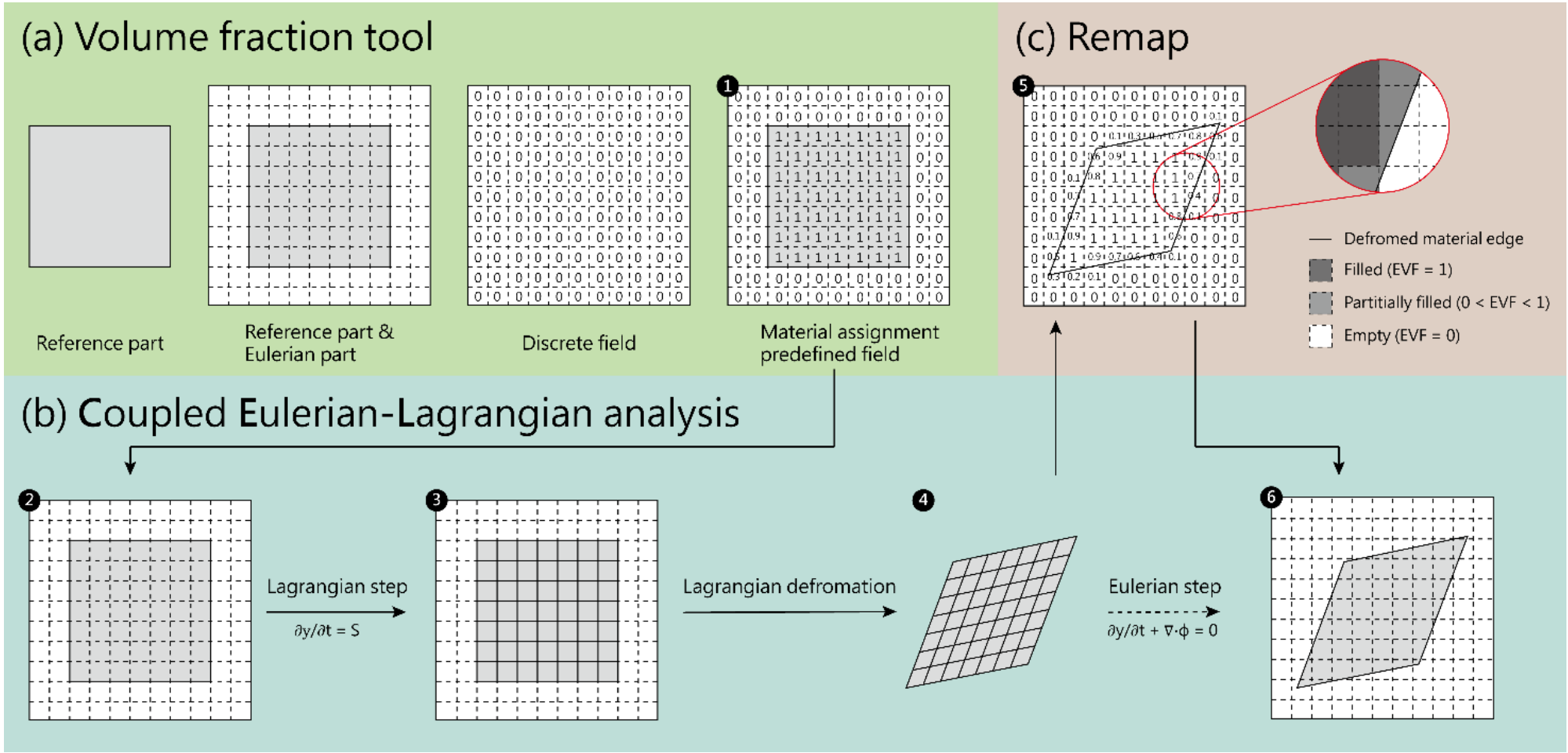


Figure 1(b). Eulerian Mesh

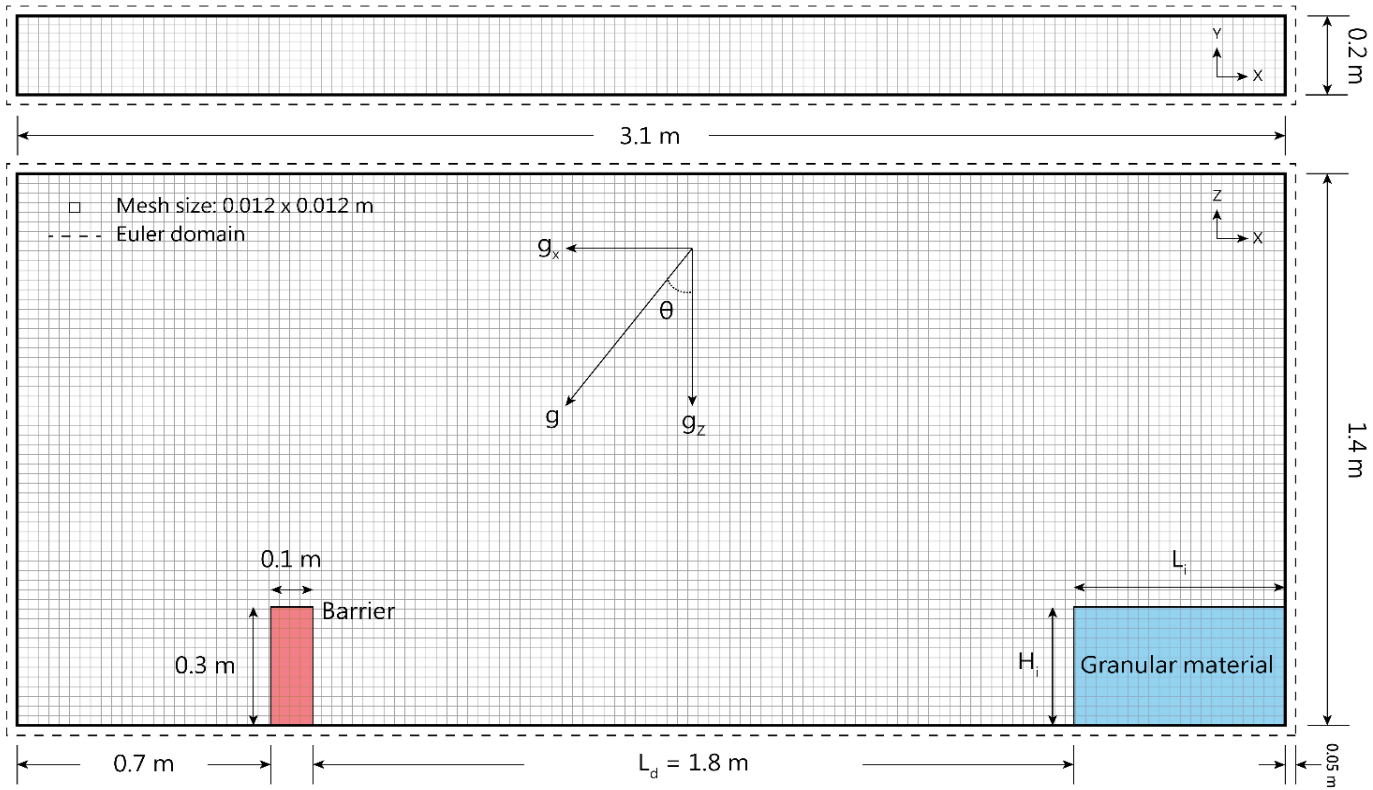
The most common mesh approach used in FEM is the Lagrangian approach (may suffer mesh distortions for large displacements)

In such cases Eulerian meshing approach is more suitable.

CEL (an updated Lagrangian method)



Design of the numerical themes



Design of the CEL model for simulating the experiments of granular column collapses and the granular flow flume tests.

the constitutive models used to simulate the granular material in the CEL analysis were the Bingham plastic model, EOS (equation of state), and Mohr-Coulomb model.

parameters of the EOS, Bingham plastic, and Mohr-Coulomb models -- requiring validations and reference.

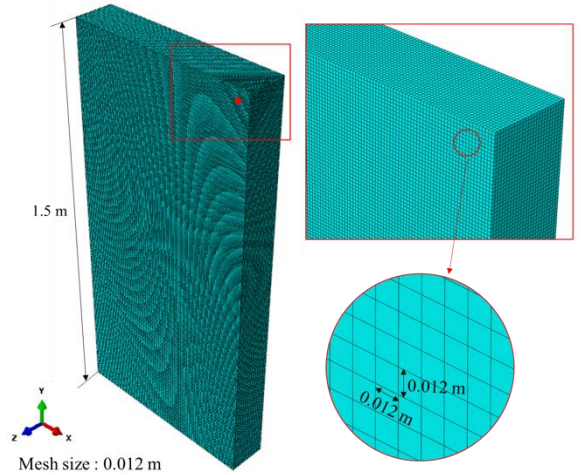
Five

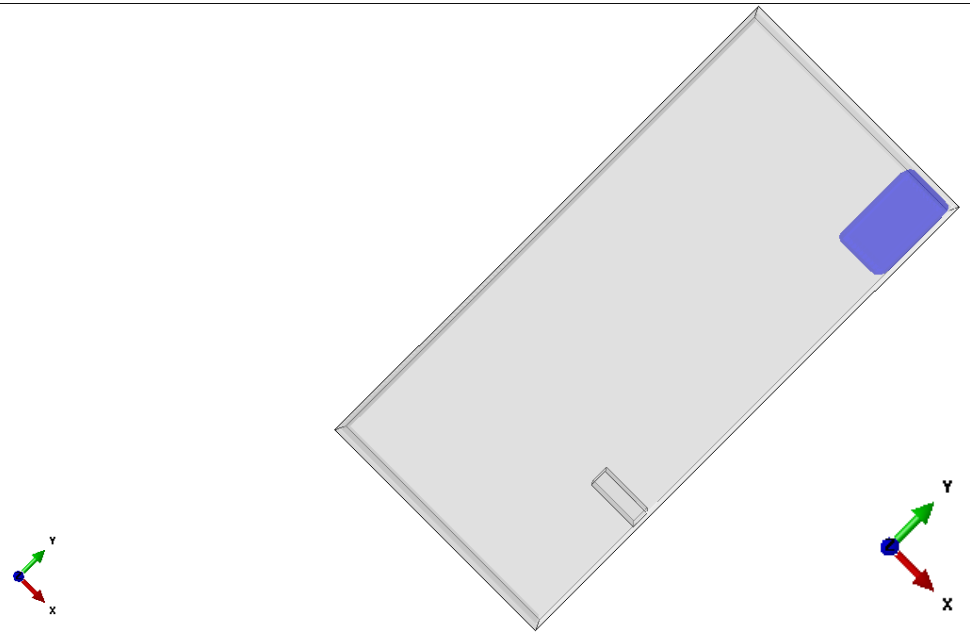
Validations & Results

VALIDATING AGAINST

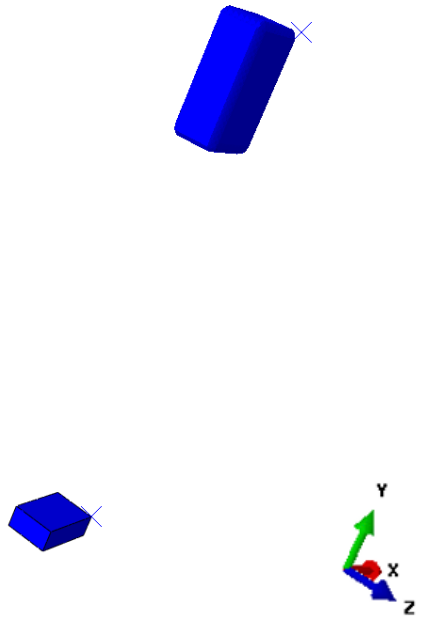
EXPERIMENTAL RESULTS

Animate $\theta=45^\circ$



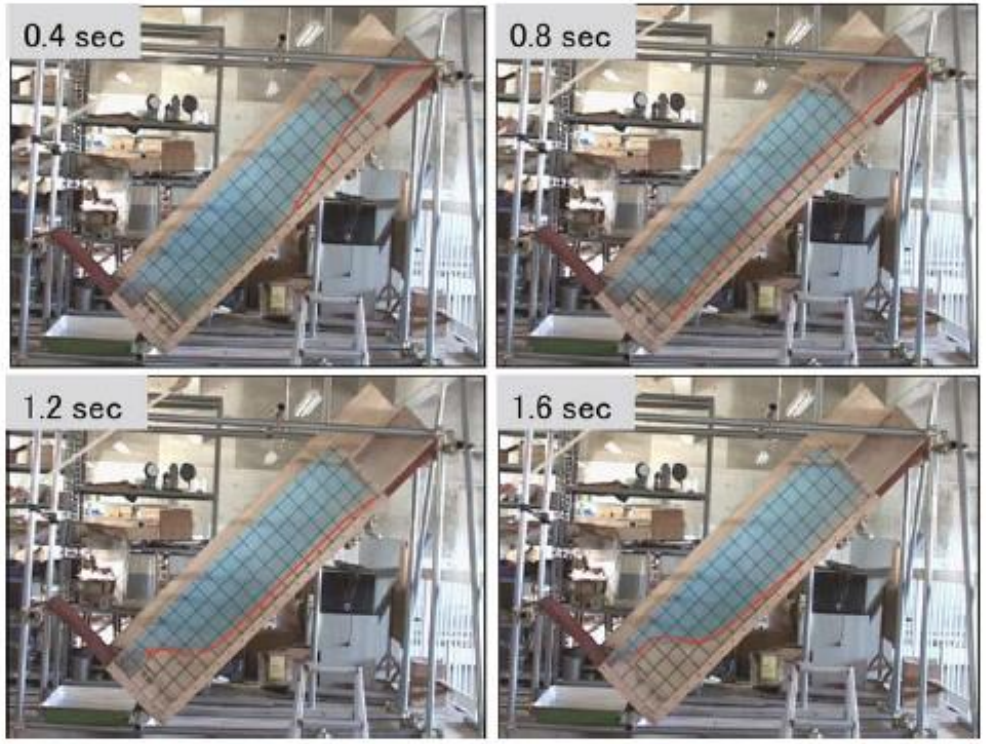


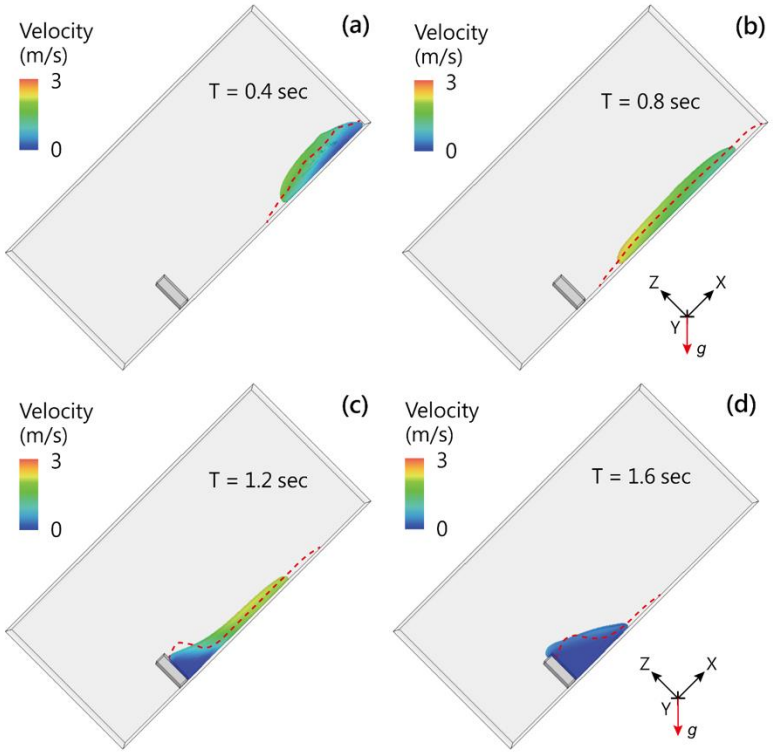
Obtained from CEL simulation

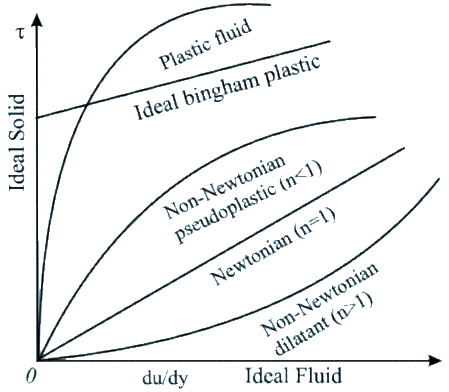


Without flume

Granular flow (after Moriguchi et al., 2009)



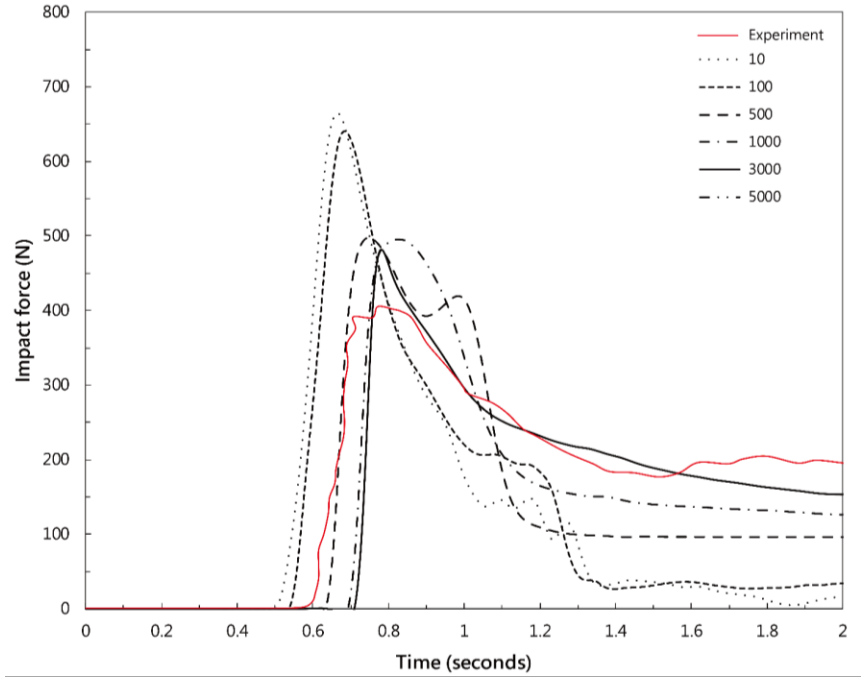




1. Validation of the flowing behavior (Bingham Plastic)

Granular flow flume (sandbox)

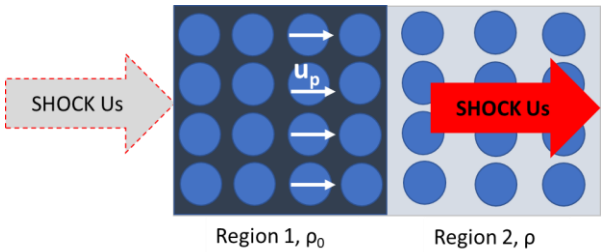
Kinematic process of the granular flow impacting a rigid wall with an inclined angle of 45°.



2. Validation of the Impact force (EOS equation; *Mie-Gruneisen*)

Dry Fine Sand				
Material Property (Moriguchi et al., 2009)	Density (kg/m^3) = 1379			
Mie-Gruneisen Equation of State				
Symbol	c_0 (m/s)	s		Γ_0
Definition	Sound speed	Slope of Us-Up relationship		Material constant
Value	100	0		0
Herschel-Bulkley fluid model				
Symbol	n*	k	η (Pa·s)	τ (Pa)
Definition	Flow index	Consistency coefficient	Viscosity coefficient	Yield shear stress
Granular Column Collapse	1	4	100	400
Granular Impact Test	1	4	100	3000

3. Calibrated material properties.



particle velocity

$$U_s = c_0 + sU_p$$

shock wave velocity

Granular column collapse

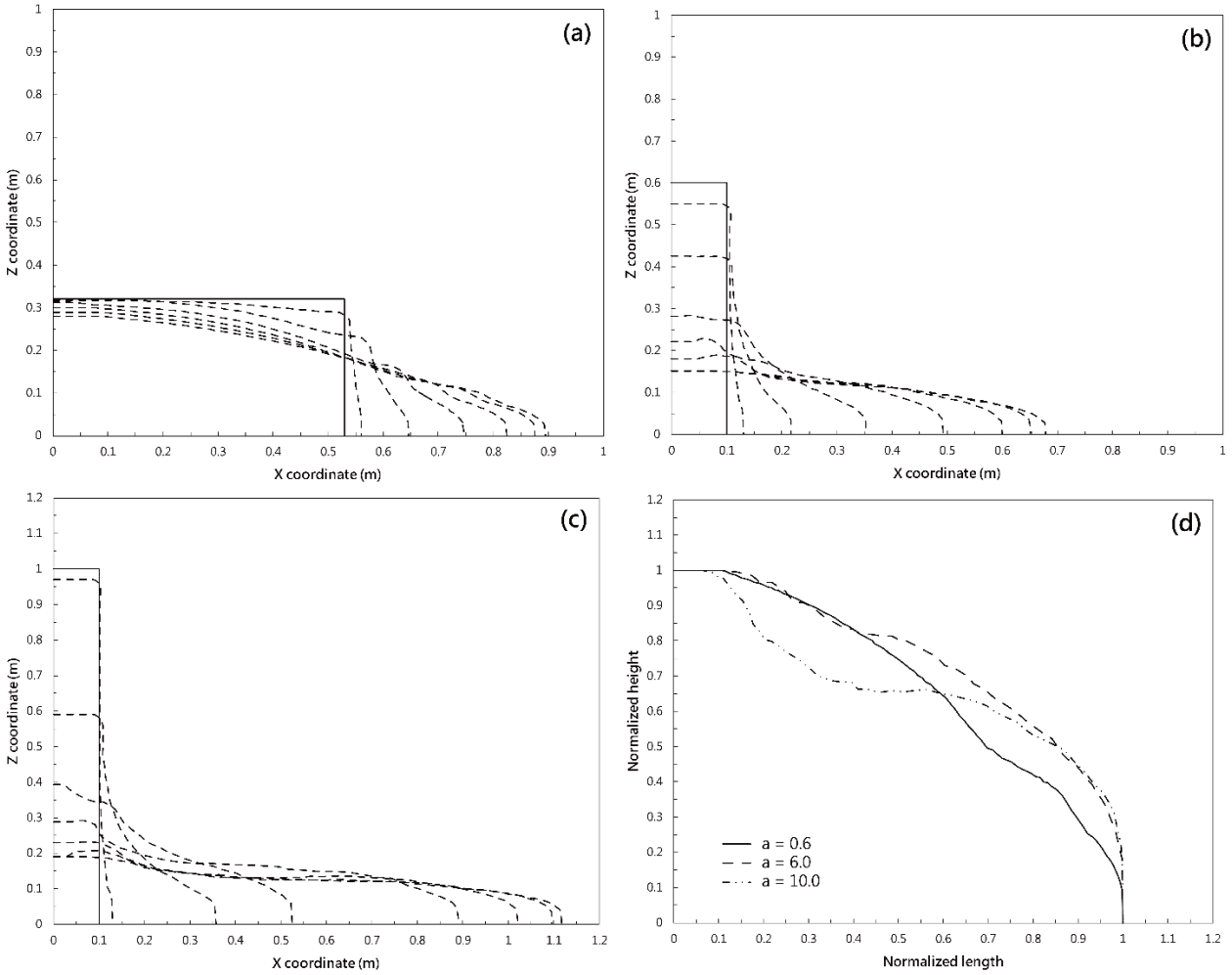
- The profile evolution of the granular column collapse at time interval of 0.1 seconds.

(a) Numerical results for a column with a = 0.6;

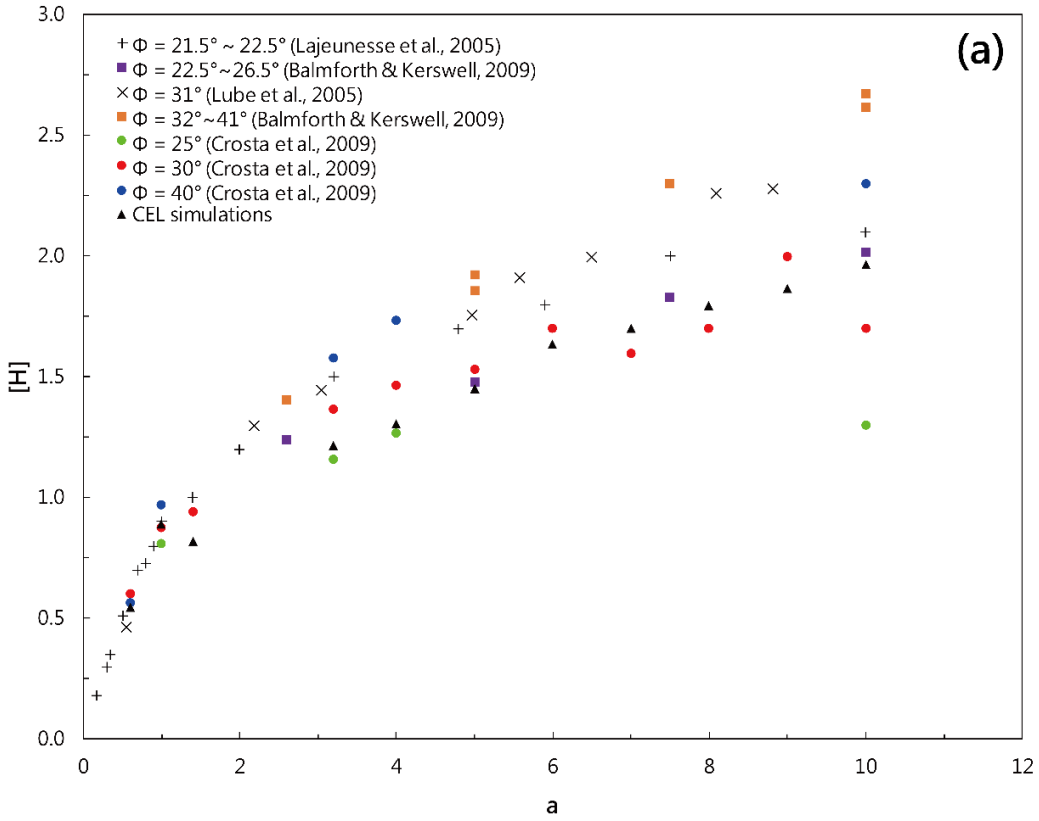
(b) Numerical results for a column with a = 6;

(c) Numerical results for a column with a = 10;

(d) Normalized profiles for the final deposit of granular materials with different a.

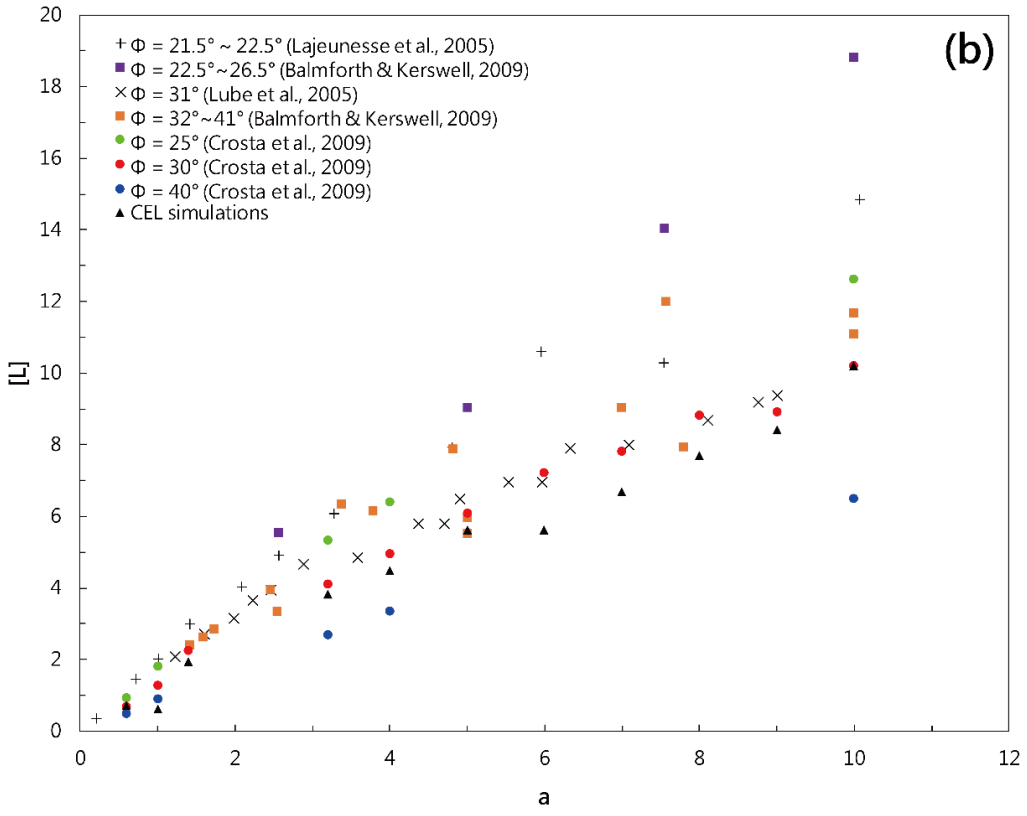


Comparison of the CEL simulation and literature data in the granular column collapse:



(a) a vs. normalized H

$$[\mathrm{H}] = \frac{H_f}{L_i}$$



(b) a vs. normalized L

$$[\mathrm{L}] = \frac{(L_{f-L_i})}{L_i}$$

AI

Must-know Elements

LIMITATIONS & APPLICATIONS

The Three Must-Know Elements of GenAI:

1. Generative Adversarial Networks (GANs), 2014

a. With 2 parts: Generator and Discriminator. A competitive process.

b. Generator: tries to create realistic data samples (make fake data).

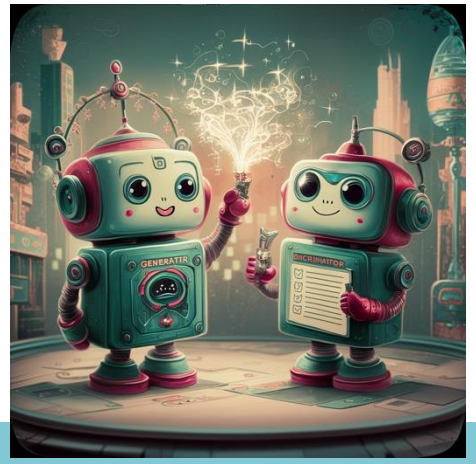
c. Discriminator: evaluates the samples for authenticity (a generator and a discriminator).

2. Variational Autoencoders (VAEs)

a. Compress and reconstruct data (machine learning)

b. Encoder: compress input data.

c. Decoder: reconstruct the original data.



3. Transformer-based models, 2017

a. Self-attention mechanisms (deep learning - **no need to labels**)

b. Capture long-range dependencies in the input data.

c. Handles sequences of variable lengths & complex relationships b/w tokens in the input.

Concluding Remarks: simulations

1. Demonstrated: proposed approach can describe *landslides holistically and provide information for better understanding landslides.*

2. Understanding landslides through physics.

3. State of the arts *tools, including AI & CEL approaches* are used to simulating the sliding behaviors.

Find purpose, the means will follow.
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