The Second Global Summit of Research Institutes for Disaster Risk Reduction
Development of a Research Road Map for the Next Decade
March 19-20, 2015

New Conceptual Model of Large-Scale Landslide

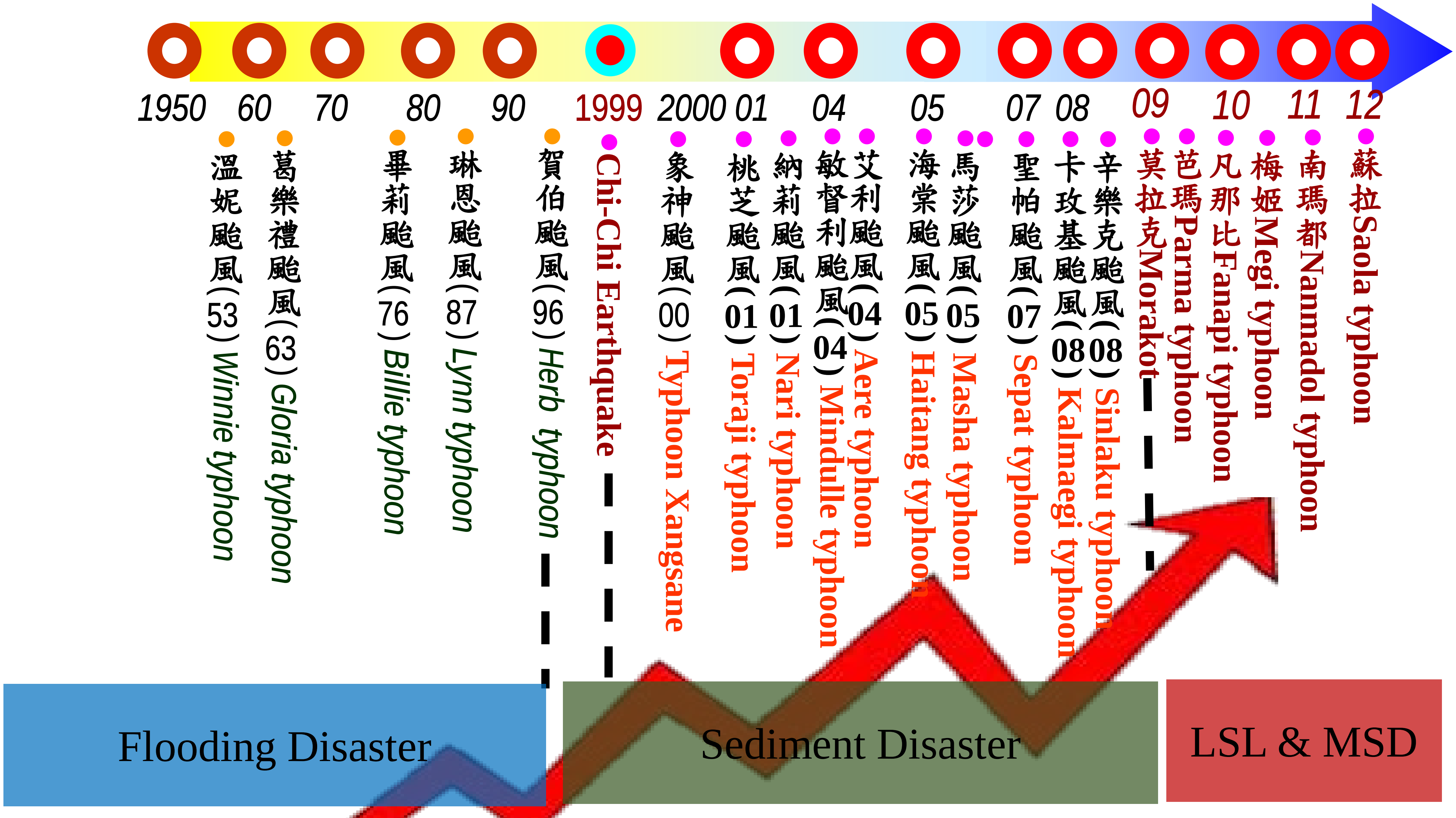
Reported by

Chjeng Lun, Shieh

Director, Disaster Prevention Research Center

National Cheng Kung University

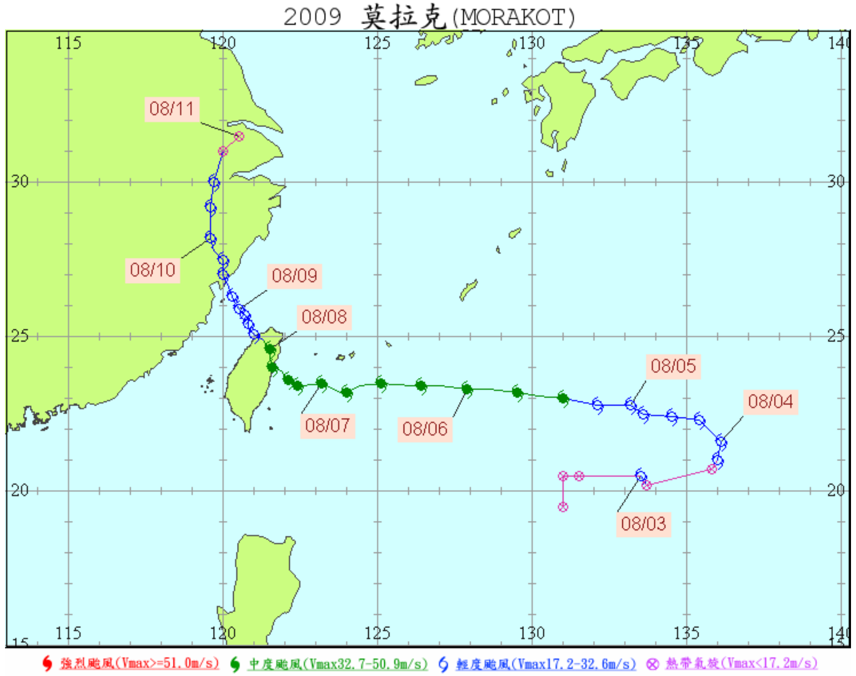
To review historical disasters from 1950, **LSL & MSD** occur frequently.



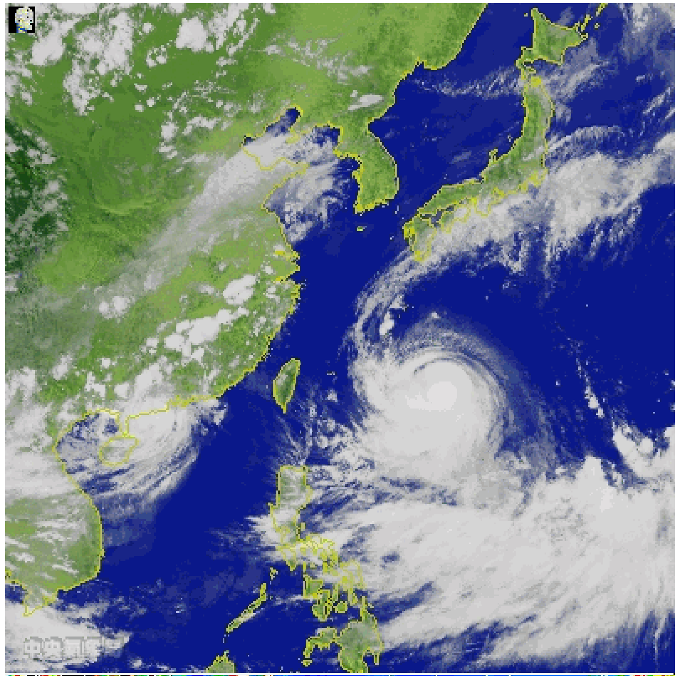
- **Background**
- Case Study
- Idea
- Experiment
- Modelized
- Solution
- Comparison
- Conclusion

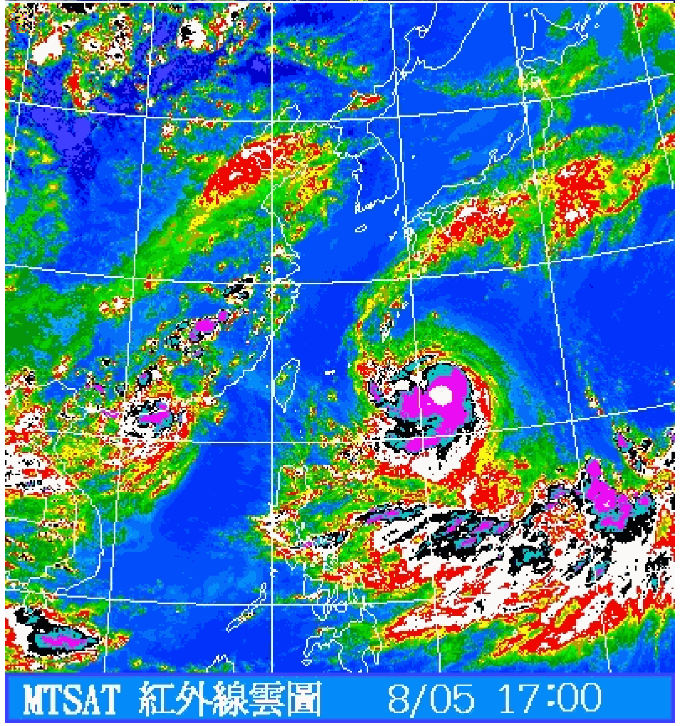
Typhoon Morakot

- The storm turned into a typhoon on Aug. 4.
- Rainfall started on Aug. 6.
- The eye of the typhoon left Taiwan from Taoyuan at 14:00 on Aug. 8.
- The rainfall continued until Aug. 10.



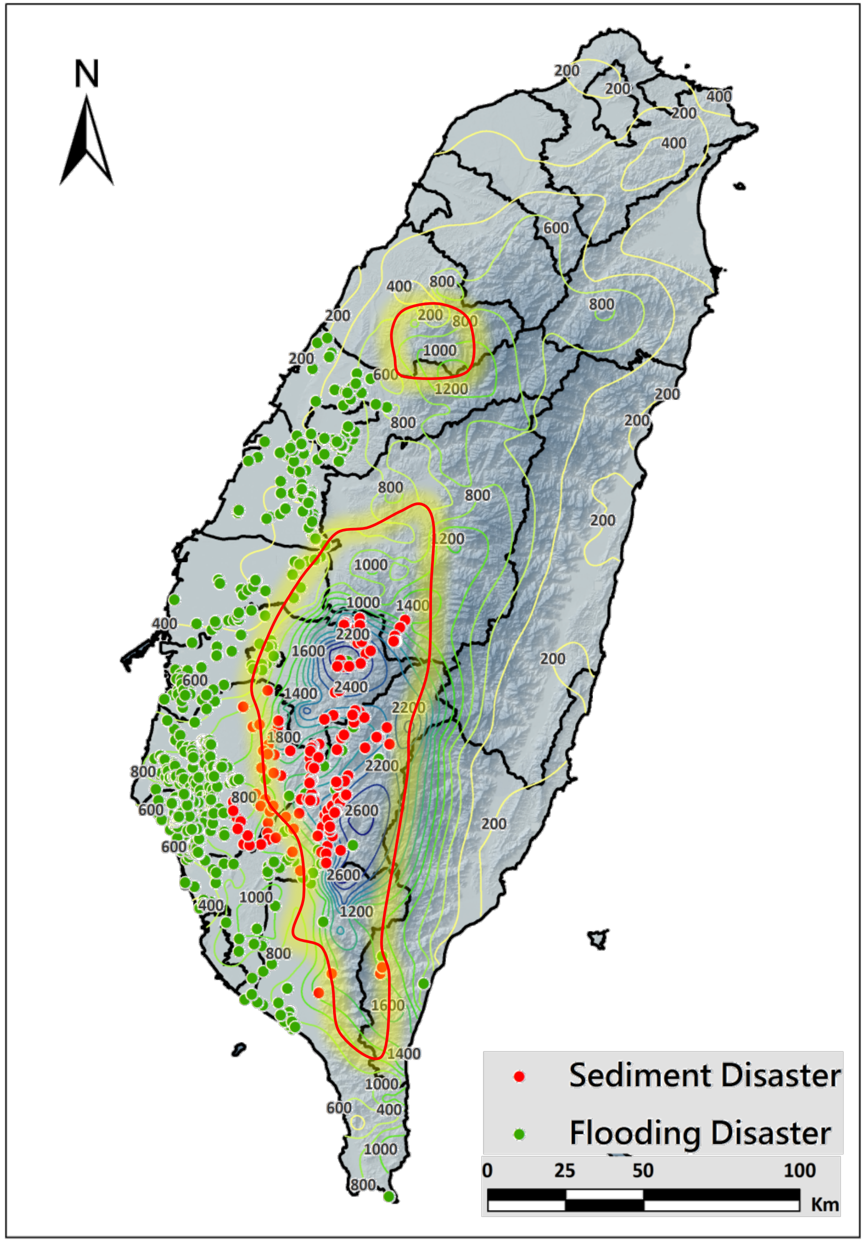
- Path of the center of Typhoon Morakot



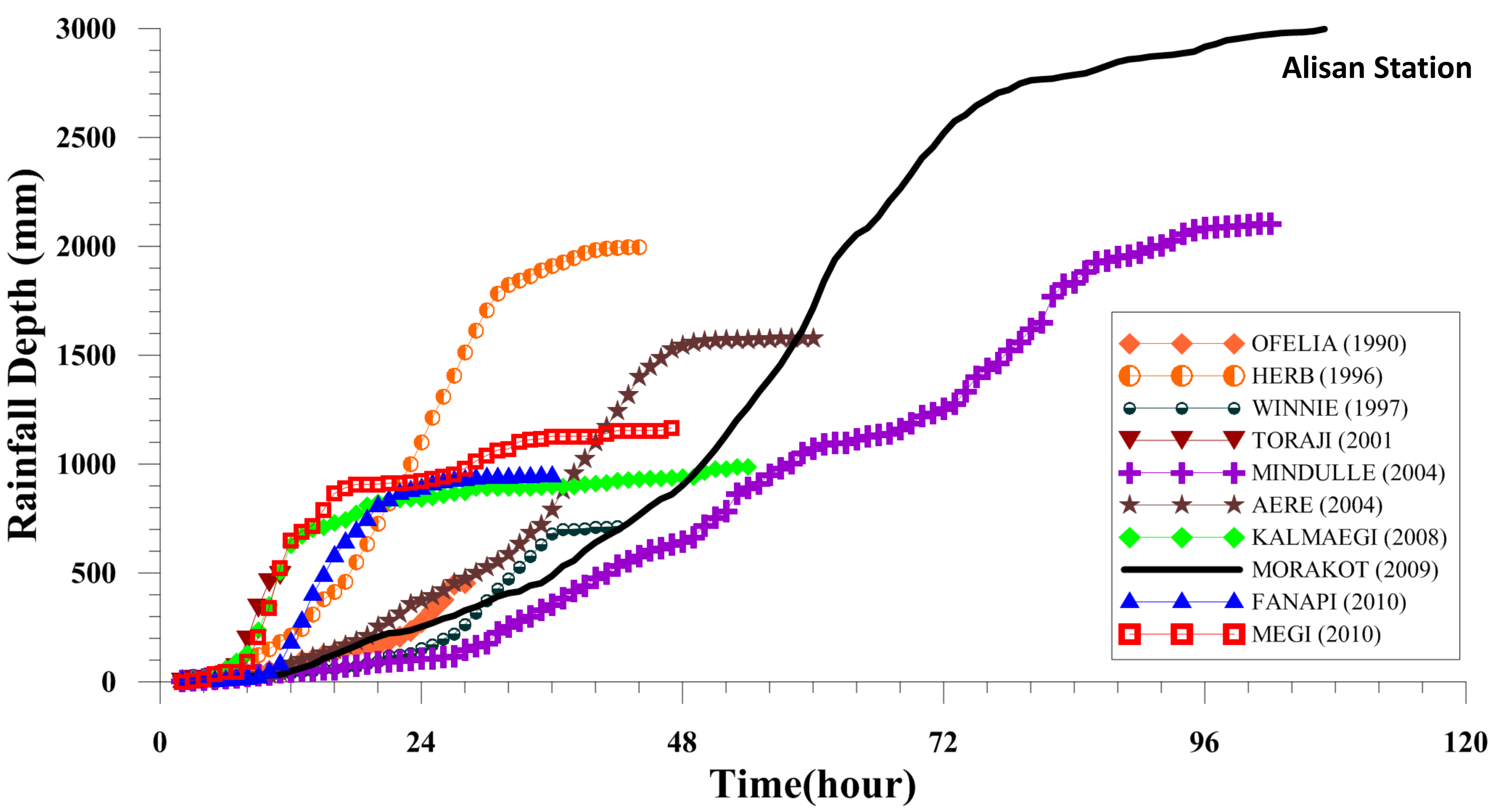


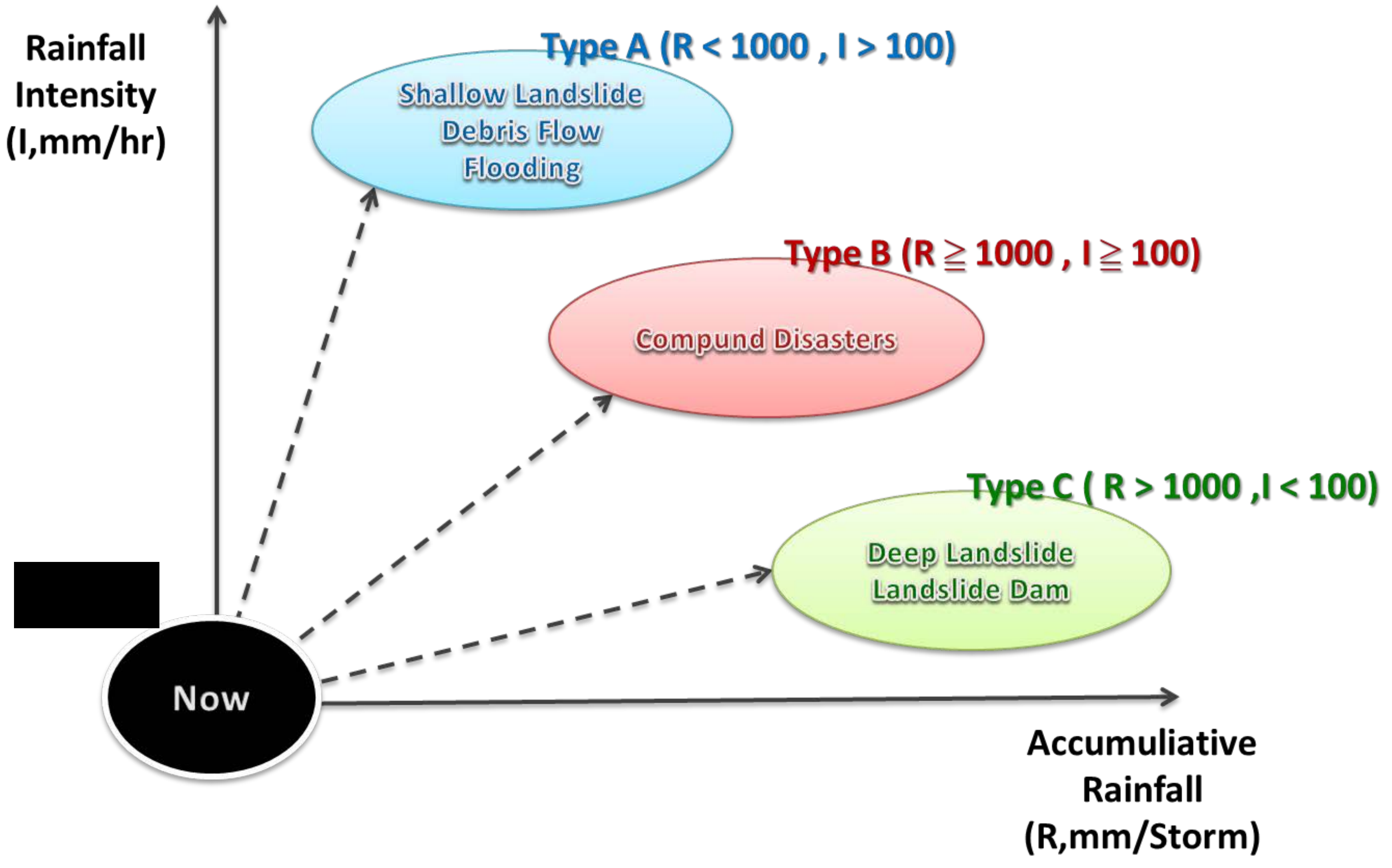
Disasters of Typhoon Morakot

- **Alisan Station**
  - Long duration (91 hours)
  - High intensity (123 mm/hour)
  - Large accumulated rainfall depth (3000 mm-72 hour)
  - Broad extent (one-fifth of Taiwan was covered)
- **Sediment-related disasters in the mountain area located within the range of precipitation > *1,000mm***
- **Inundation area located at the downstream of rainfall center in the plain area**



The relationship between accumulative rainfall and duration of catastrophic typhoons




Rainfall Intensity (I,mm/hr)
Type A (R < 1000 , I > 100)
Shallow Landslide
Debris Flow
Flooding
Type B (R ≧ 1000 , I ≧ 100)
Compund Disasters
Type C (R > 1000 ,I < 100)
Deep Landslide
Landslide Dam
[redacted]
Now
Accumuliative Rainfall (R,mm/Storm)

- Shieh, 2012

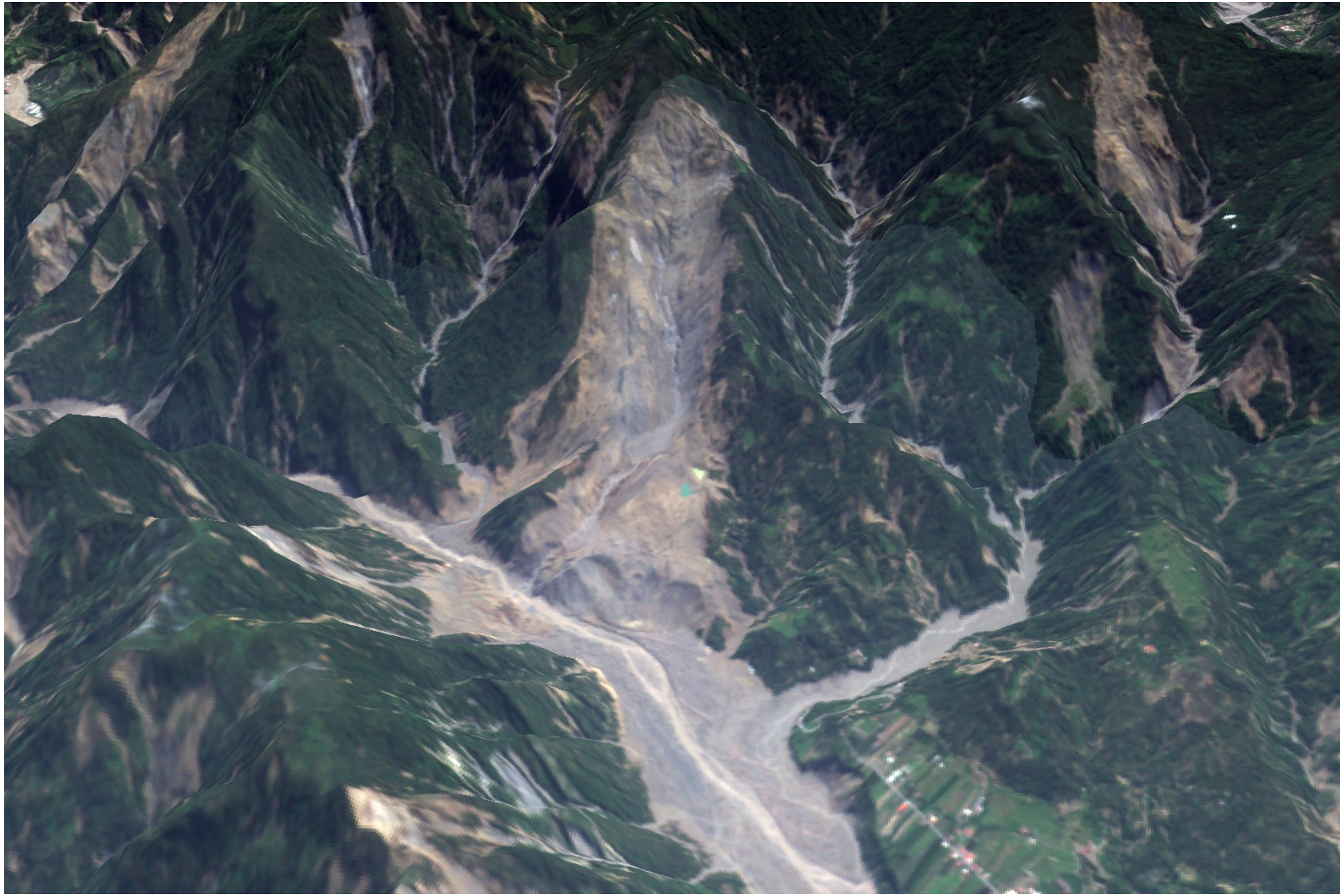
The scale and type of the disaster increasing with the frequent appearance of extreme weather

Large-scale landslide and compound disaster become a new challenge

- Area：202 ha Depth：80 meter Volume： 24 million m^3

Before Typhoon Morakot in Hsiaolin Village
(FORMOSAT-2)

After Typhoon Morakot in Hsiaolin Village
(FORMOSAT-2)



LESSONS FROM THE DISASTER OF HSIAOLIN VILLAGE

- **Compound Disaster, included shallow landslide, debris flow, flooding, large-scale landslide, natural dam break, occurred in Hsiaolin village**
- **The main disaster is caused by large-scale landslide.**

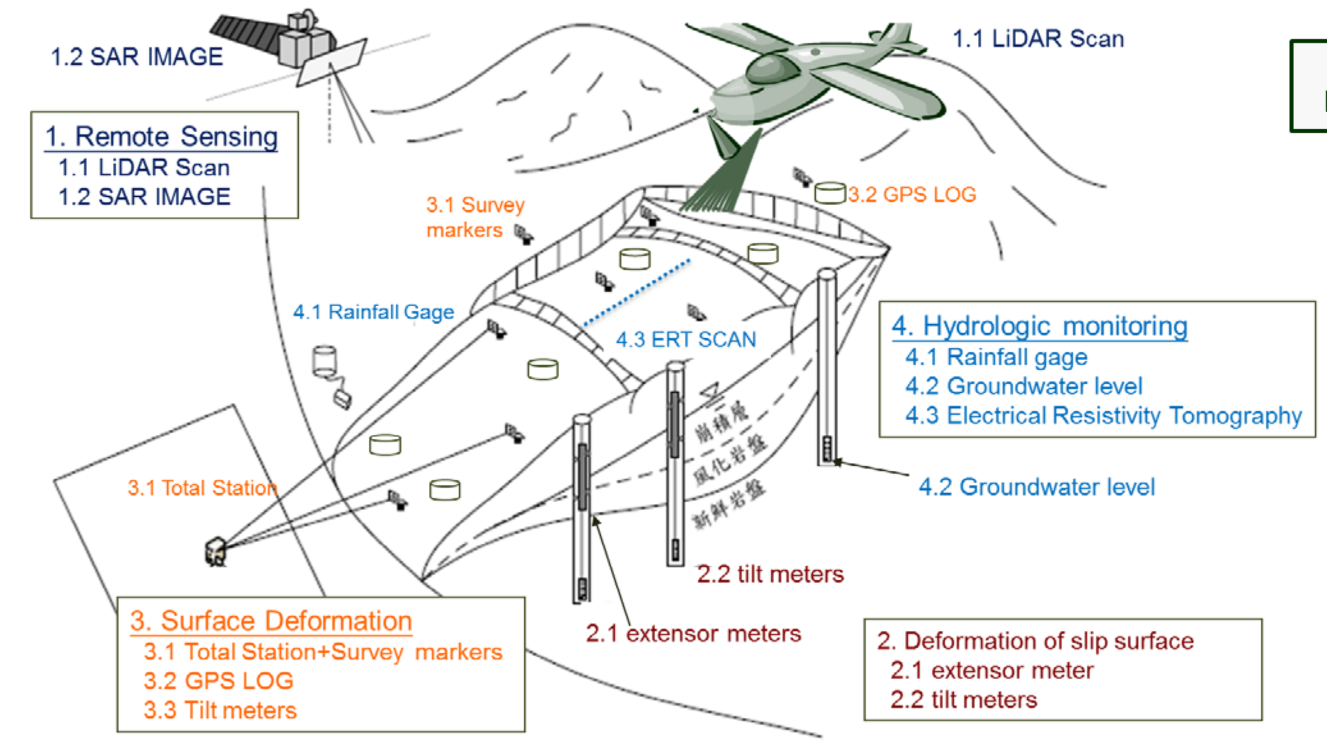
↓

Mitigation Strategies of Large-scale Landslide Disaster in Taiwan

IDEA FOR MITIGATION STRATEGIES OF L.S.L.
(6Ws1H)

- Where → Potential Area
- What → Risk analysis (Influence Area)
- Why → On-site monitoring
- When → Forecast and Warning System
- Who → Evacuation Plan
- How → Training, Drills, Education

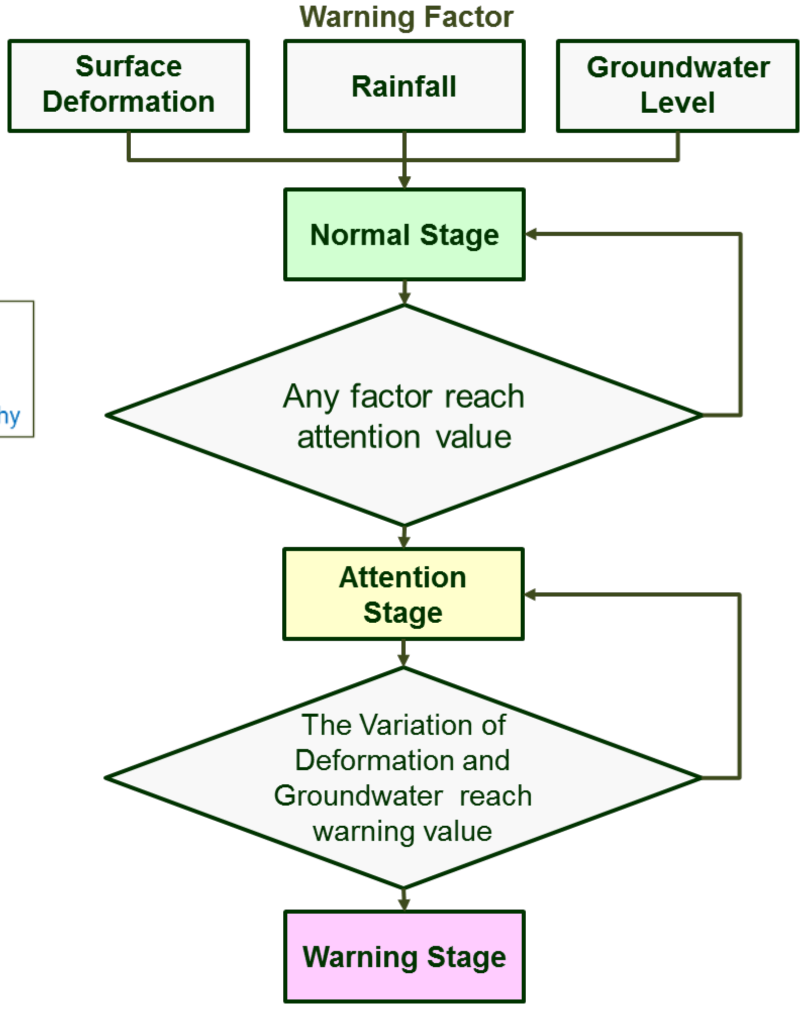
On-site monitoring



All the monitor result to setup the warning system, such as rainfall, groundwater level, surface deformation.

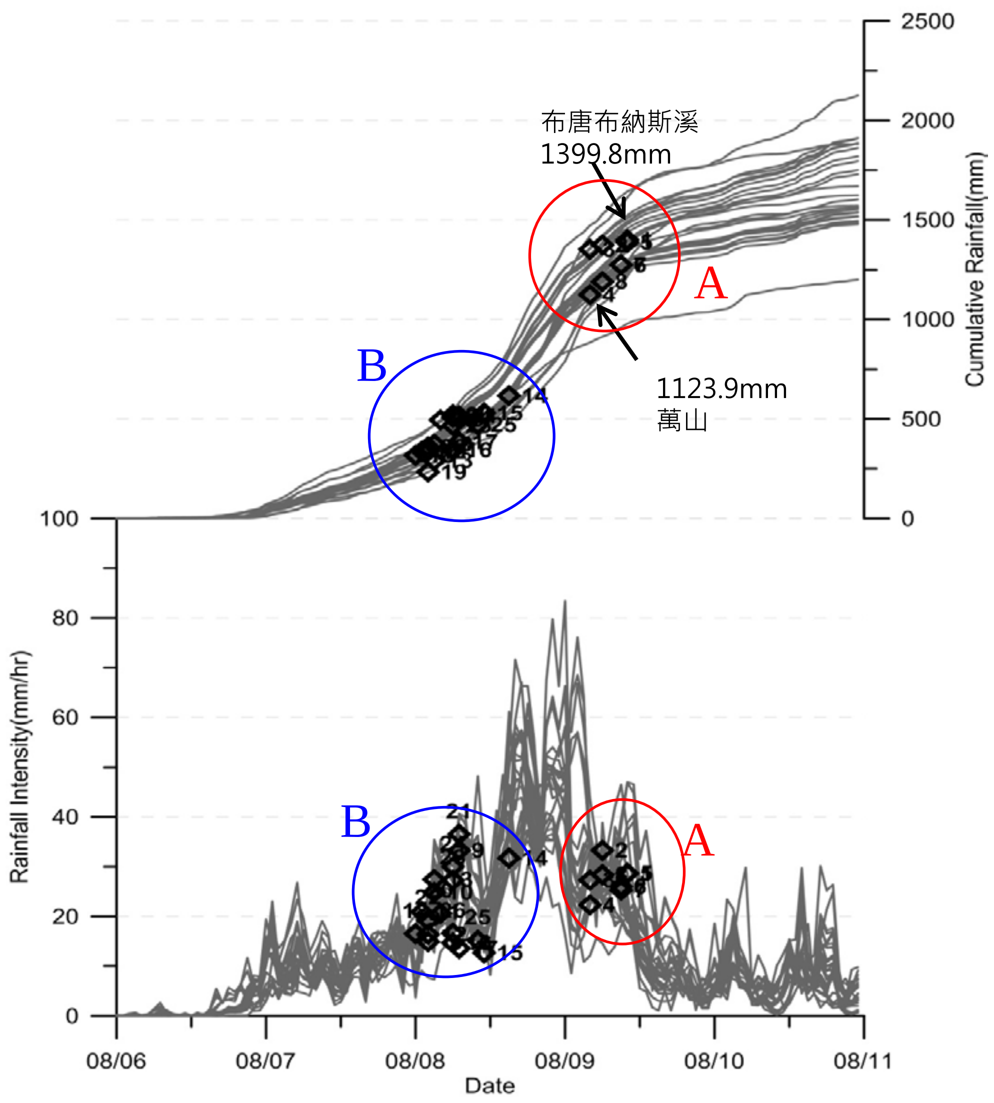
How to combine all the result together?

Forecast and Warning System



- To Review Landslide cases in typhoon Morakot, 2009

- **Group A is classified as new born landslide, and group B include enlarge case and combine case**
- **New Born Case**
  - ☐ **Cumulative rainfall >1,000 mm**
  - ☐ **After rainfall peak**
  - ☐ **near the turning point of accumulative rainfall**
- **Enlarge & Combine case**
  - ☐ **Cumulative rainfall is about 300- 500 mm**
  - ☐ **Before rainfall peak**



Case Study of Large-scale Landslide in Taiwan

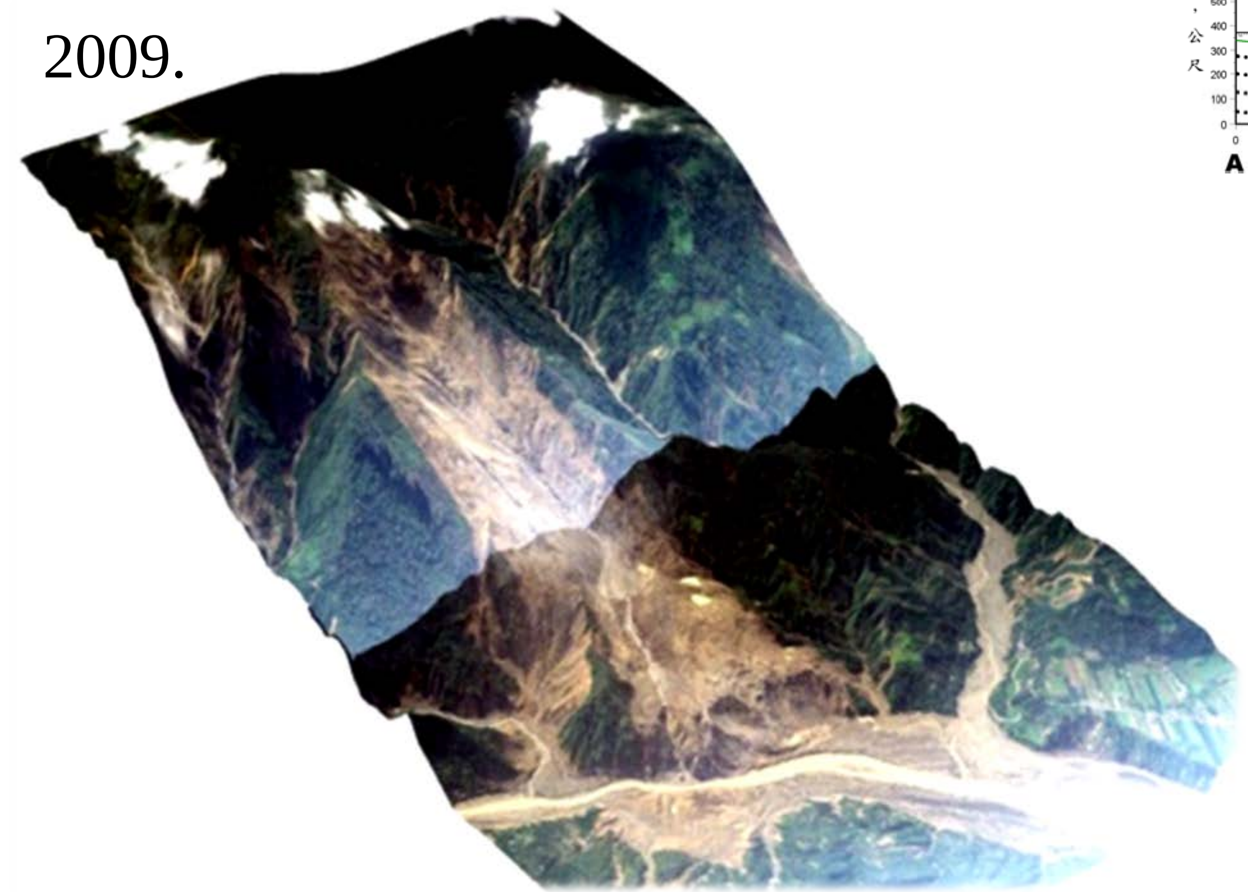
Definition of Large-scale Landslide

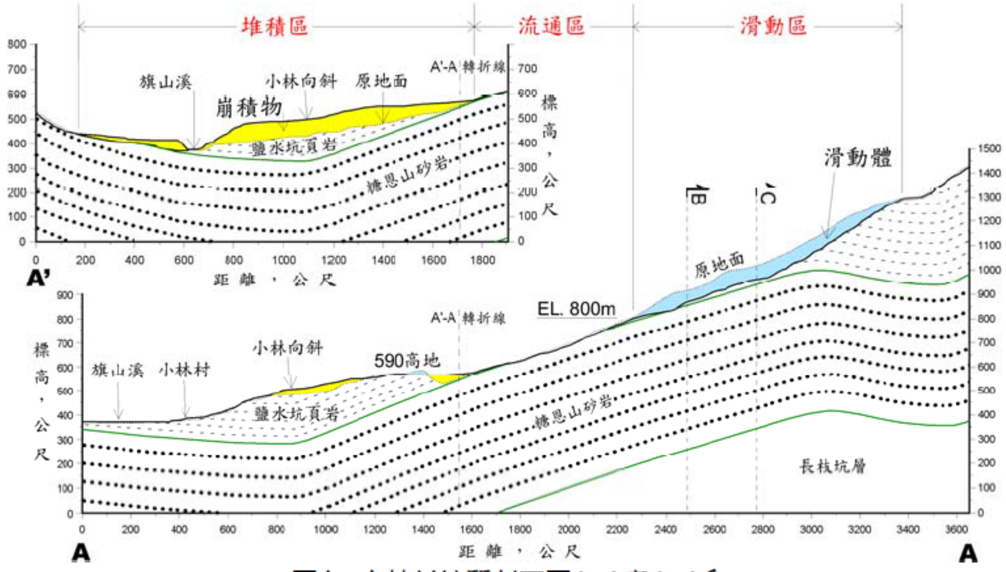
Area > 10 ha

Depth > 10 m

Volume > 10^4 m^3

- Fast-moving landslide was caused by typhoon.
- Hsiaolin Village, Kaohsiung County in 2009.





圖九 小林村地質剖面圖A–A與A–A´

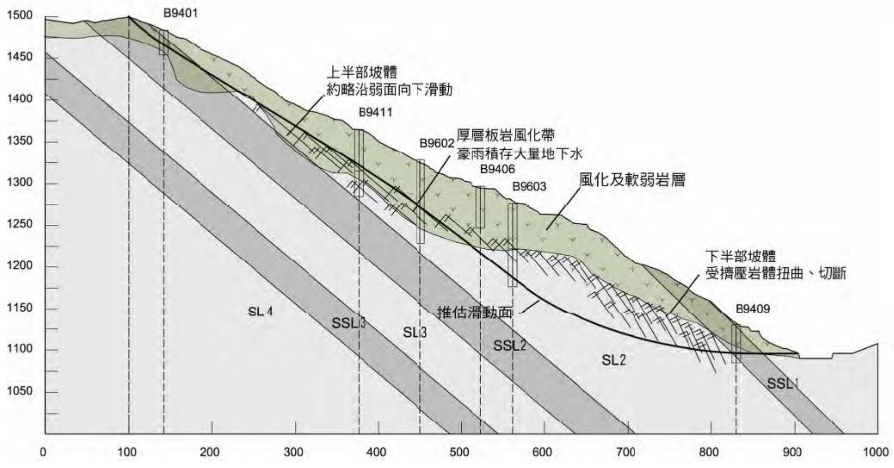
- **Time：August/06-10 (Typhoon Morakot)**
- **Area of landslide：202 ha**
- **Depth of landslide：80 m**
- **Slope：26°**
- **Movement Distance： 2000 m**
- **Accumulative Rainfall：2583 mm**
- **Loose soil mass**
- **With the imprint of groundwater**

- Fast-moving landslide was caused by typhoon
- Taimali River, Taitung County in 2009

- Time：August/06-10 (Typhoon Morakot)
- Area of landslide：290 ha
- Depth of landslide：200 m
- Slope：22°
- Movement Distance： 1000 m
- Accumulative Rainfall：1400 mm
- Loose soil mass
- With the imprint of groundwater

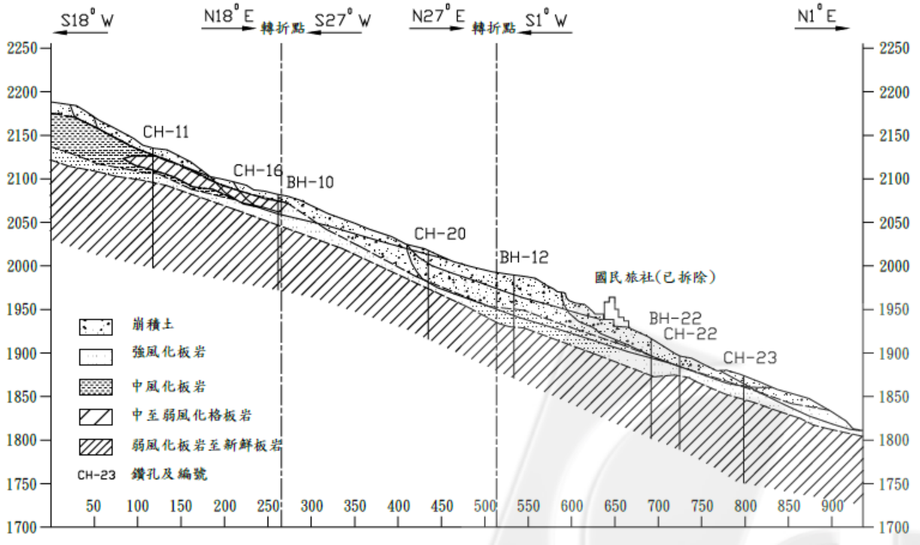
- Slow-moving landslide was caused by rainfall
- Lushan landslide, Nantou since 1994

盧山地滑監測及後續治理規劃，黎明工程，2003



- **Area of landslide：30 ha**
- **Depth of landslide：~100 m**
- **Slope：26°**
- **Mass movement**
- **With the imprint of groundwater**

- Slow-moving landslide was caused by rainfall
- Li-San landslide, Taichung, since 1990

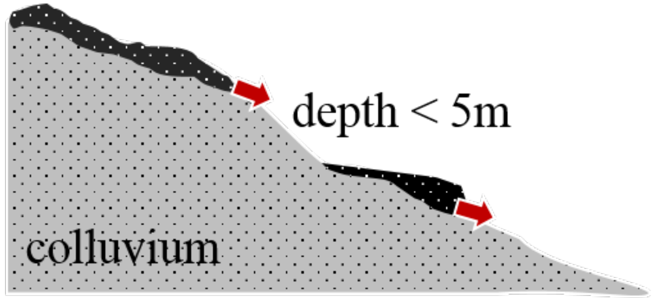


- **Area of landslide：230 ha**
- **Depth of landslide：~50 m**
- **Slope：20°**
- **Movement Distance：800 m**
- **With the imprint of groundwater**

中華水土保持學報，颱風降雨期間梨山地滑區邊坡穩定性之數值評估，2008

Similarity of F.M.L and S.M.L.

Shallow Landslide (fast-moving landslide)



The Experimental Forest, NTU(2012 yr.)

Occurrence: < 2 days(Typhoon Saola) without the groundwater layer

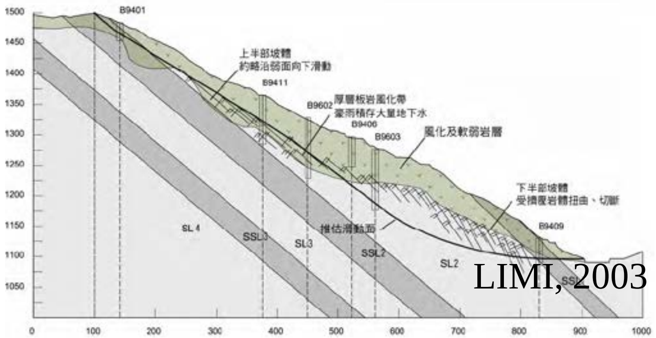
Slope = $22^\circ \sim 29^\circ$

$\phi \approx 25^\circ$

$i_p = 99.5$ mm/hr

$P = 1132$ mm

Large-scale Landslide (slow-moving landslide)



Lushan landslide

Occurrence: For decades
with the imprint of groundwater

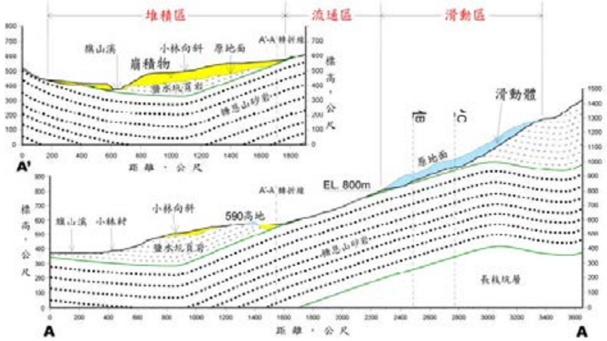
Slope = $24^\circ \sim 26^\circ$

$\phi_r \approx 22^\circ \sim 27^\circ$

$i_p = 30 \sim 35$ mm/hr(2005~6 yr.)

$P = 820$ mm (2006 yr)

Large-Scale Landslide (fast-moving landslide)



Hsiaolin Village(2009 yr.)

Occurrence: 4 days (Typhoon Morakot)
with the imprint of groundwater

Slope = 26°

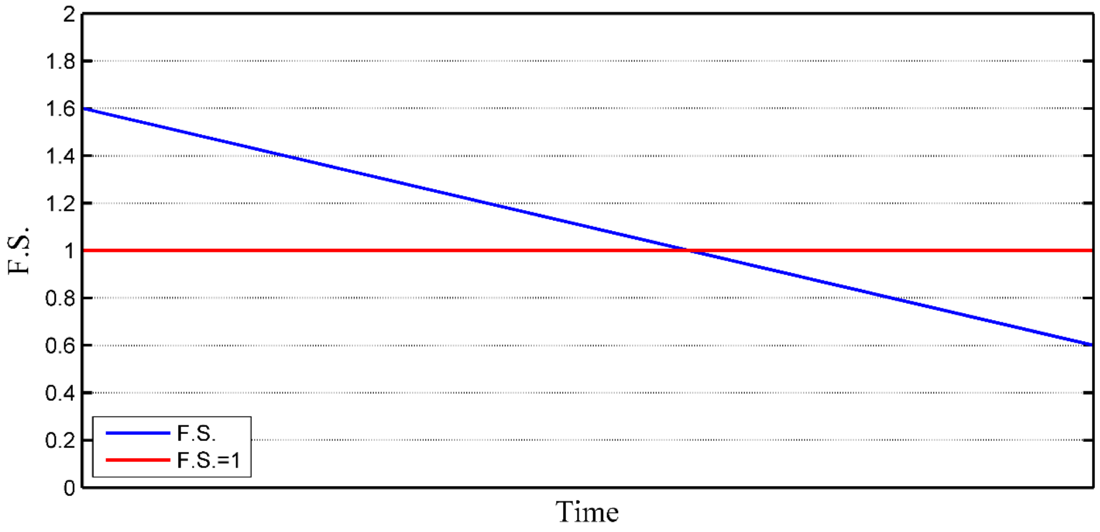
$\phi_r \approx 21^\circ \sim 25^\circ$

$i_p = 103$ mm/hr

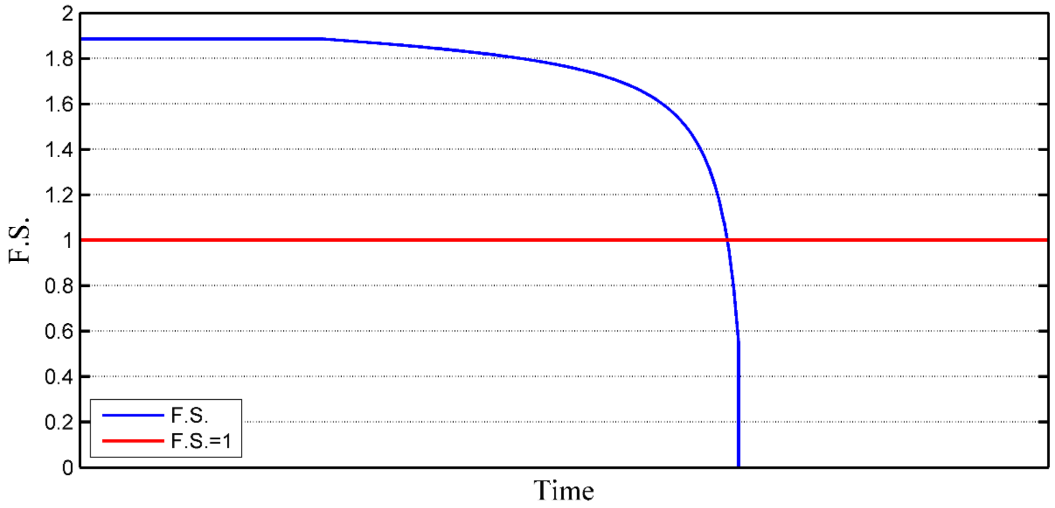
$P = 2583$ mm

Difference of F.M.L. and S.M.L.

S.M.L



F.M.L



Safety Factor $FS = \frac{R}{D}$

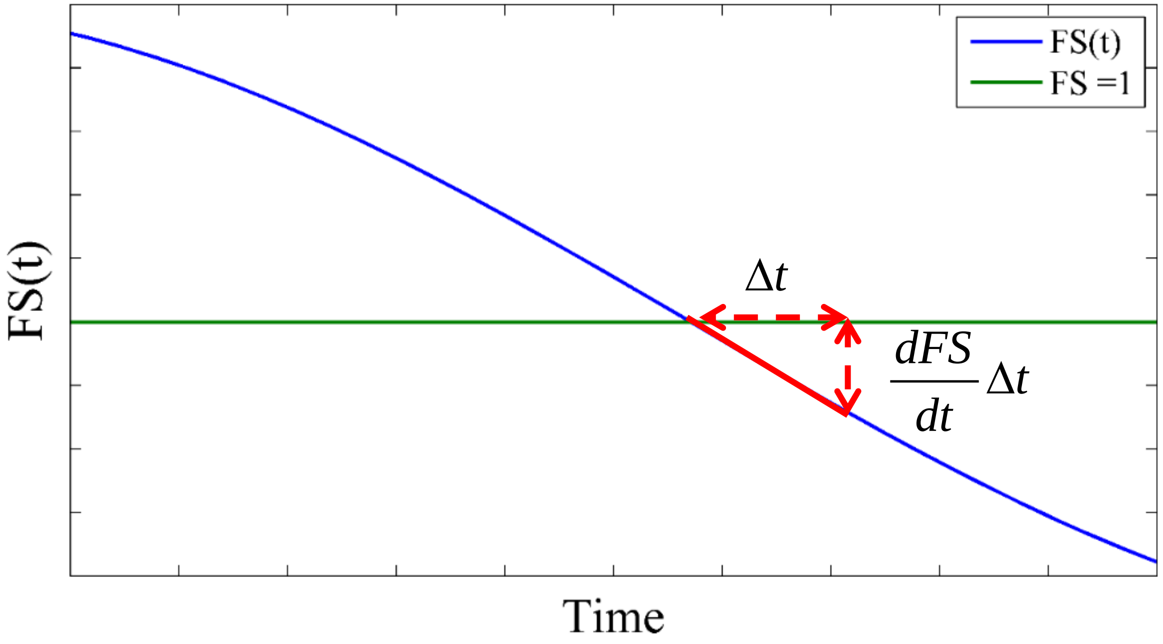
$$D - R = (1 - FS)D = \text{Net force acting on sliding block} = Ma$$

$$\Rightarrow \frac{D}{M}(1 - FS) = a, \text{ where } 1 - FS = \frac{dFS}{dt}\Delta t$$

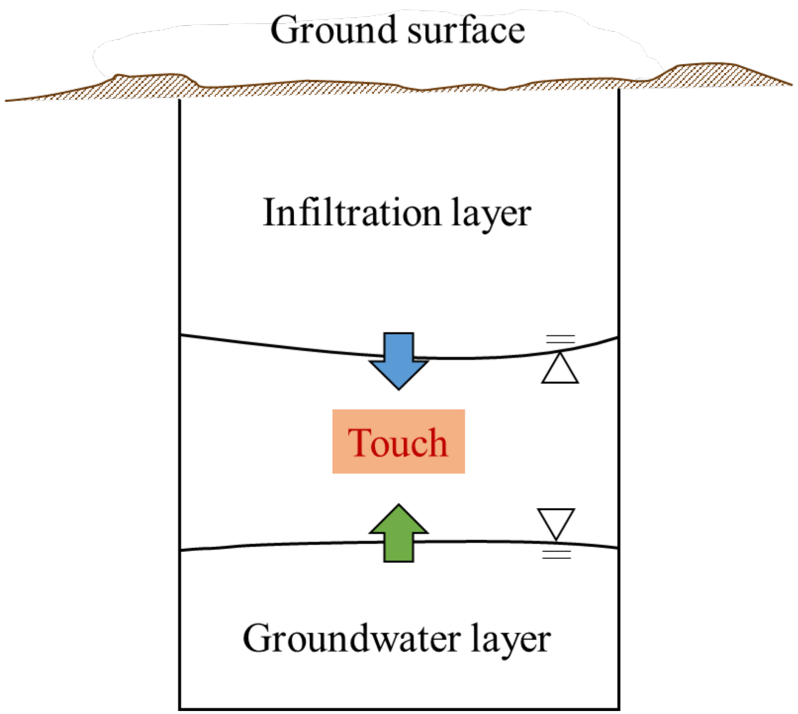
$$\Rightarrow a = \frac{D}{M}\frac{dFS}{dt}\Delta t$$

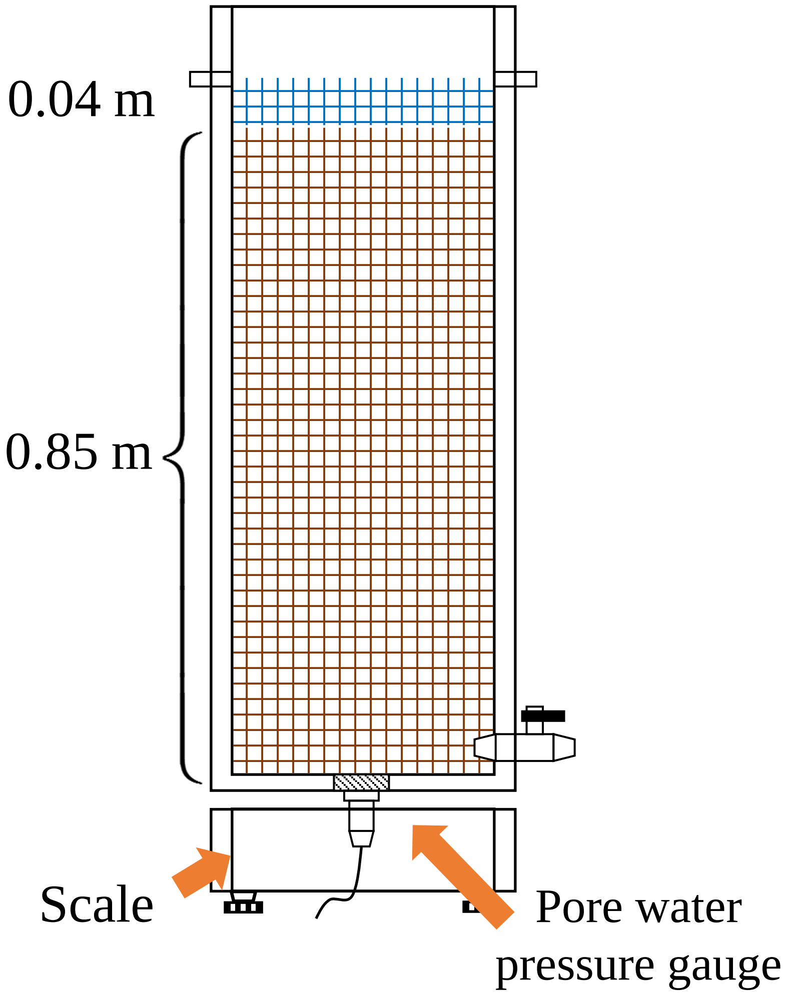
$$\Rightarrow a \propto \frac{dFS}{dt}$$

D: Driving Force
R: Resistance Force
M: Mass of sliding block



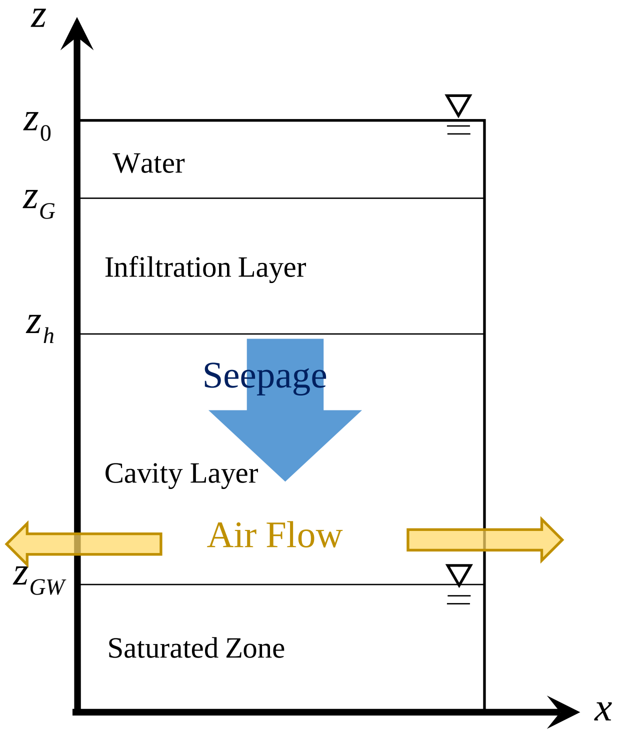
- The flow velocity of infiltration and groundwater is usually small, therefore, what's reason causes the rapid decreasing in F.S.?
- We are interesting in what kinds of interaction between infiltration and groundwater will trigger sudden failure or creeping landslide.



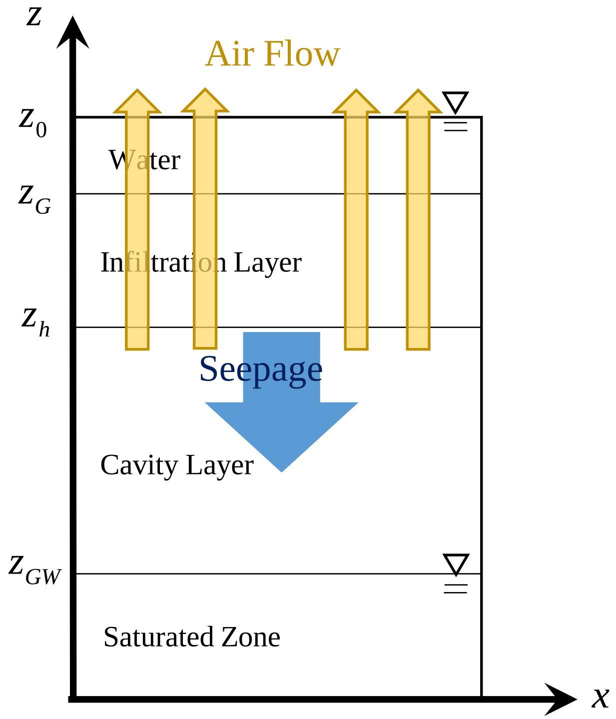


Experiment measure data $\begin{cases} W_{sc}: \text{ weight} \\ p_{wb}: \text{ porewater pressure} \end{cases}$

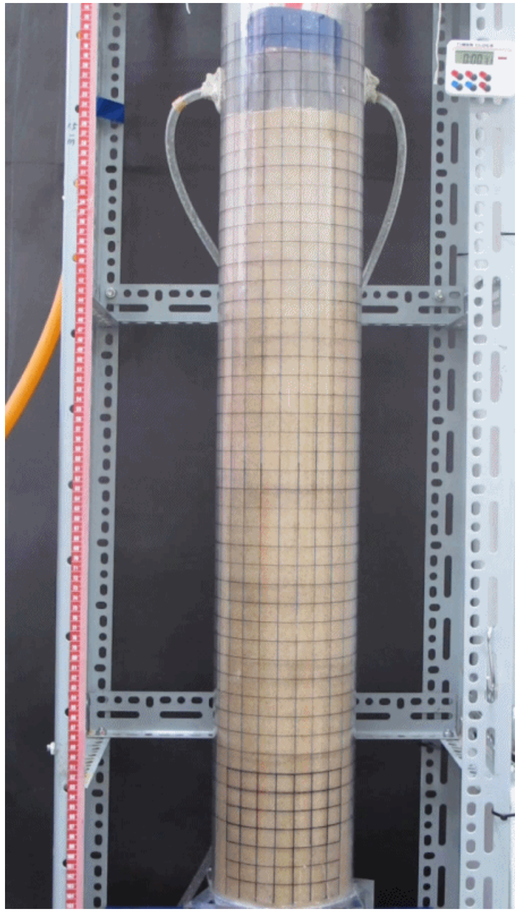
Case I：Air escape from bottom

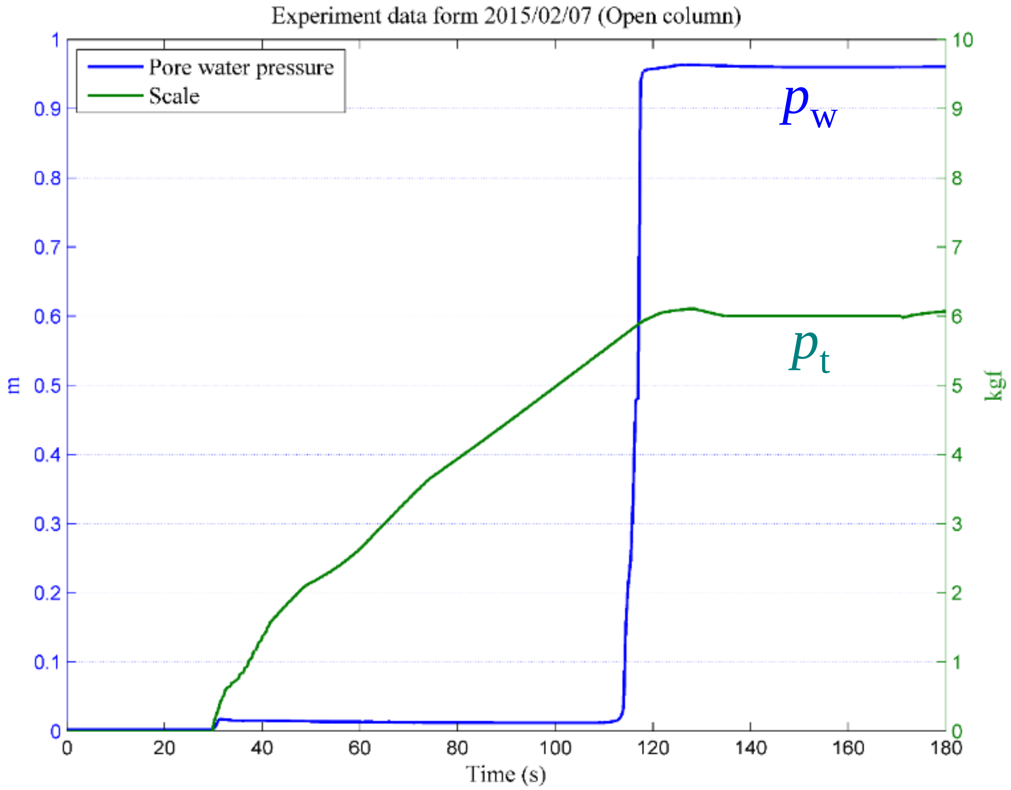


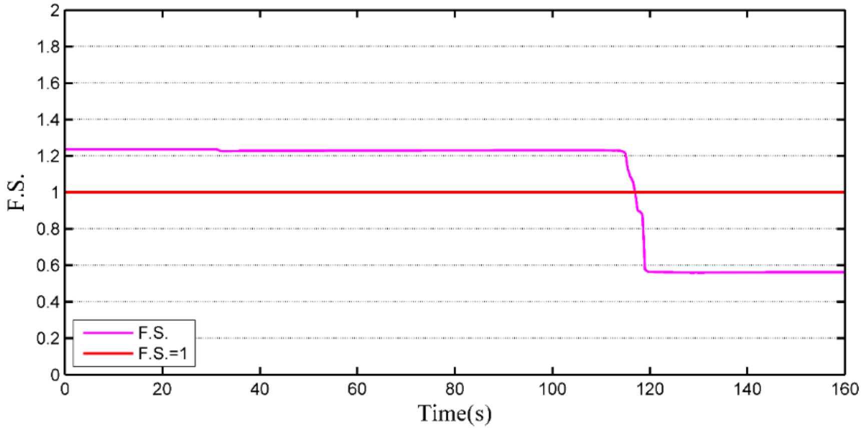
Case III：Air escape from top



Case I: Air escape from bottom





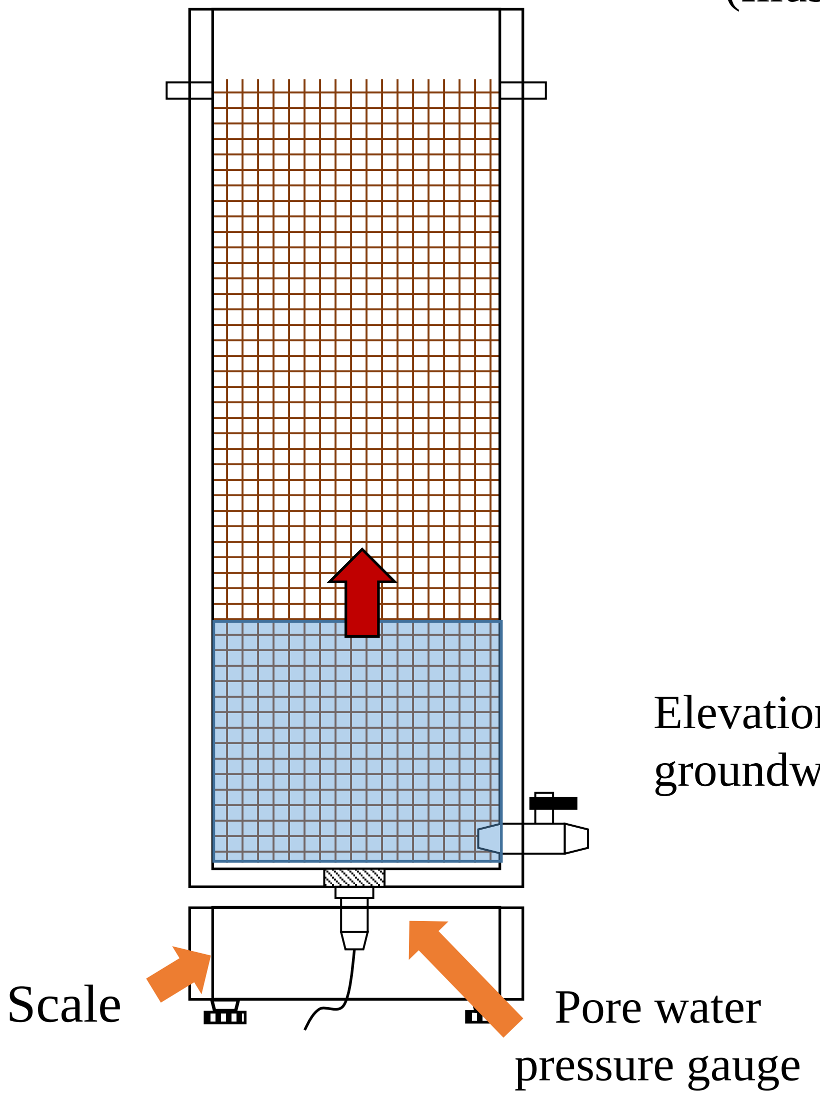


$$\text{S.F.}=\frac{c+\{(1-n)\gamma_s L_s + Sn\gamma_w h(t) - p_w(t)\}\tan\varphi\cos\theta}{\{(1-n)\gamma_s L_s + Sn\gamma_w h(t)\}\sin\theta}$$

where, $\varphi = 25^\circ; \theta = 30^\circ; c = 0.$

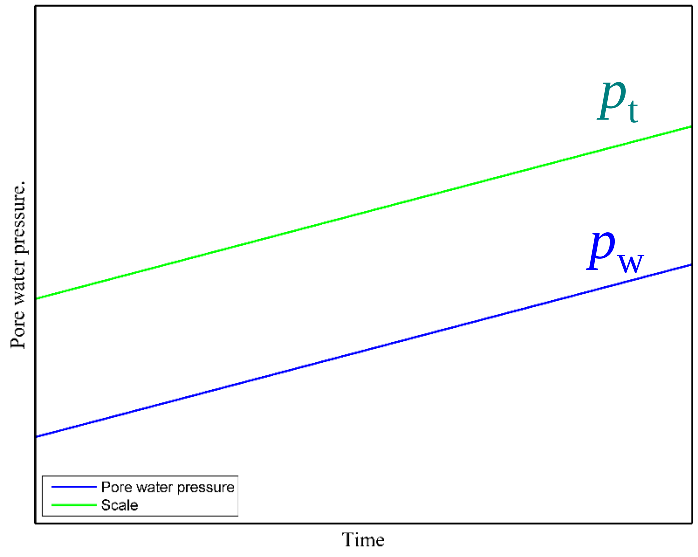
Case II: Groundwater upwelling

(Illustration)

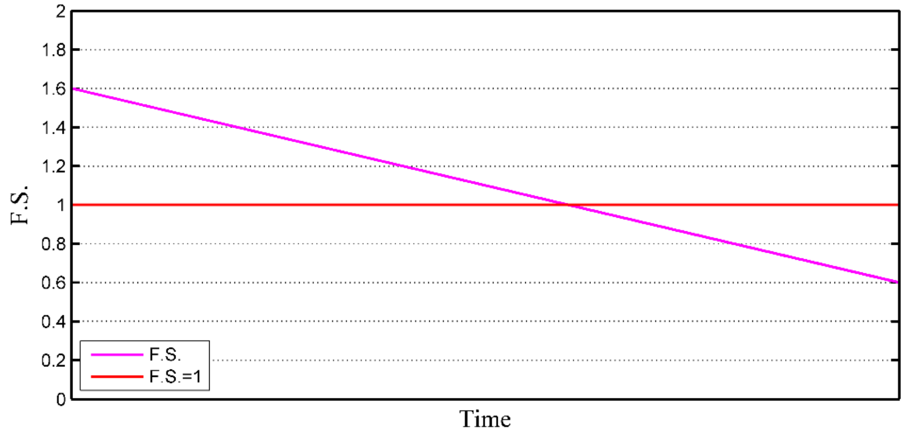


Elevation controlling of groundwater

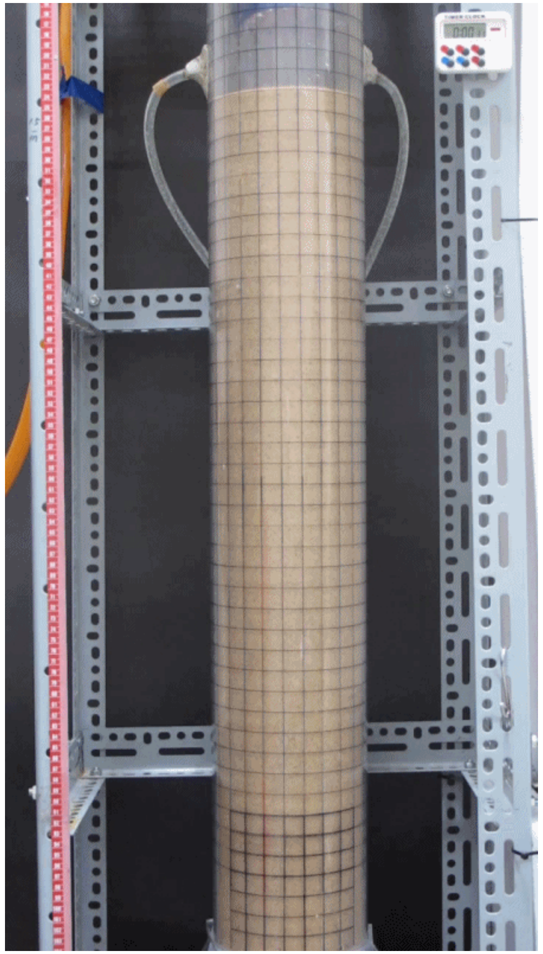
Anticipation of change in pore water pressure



Anticipation of change in S.F.

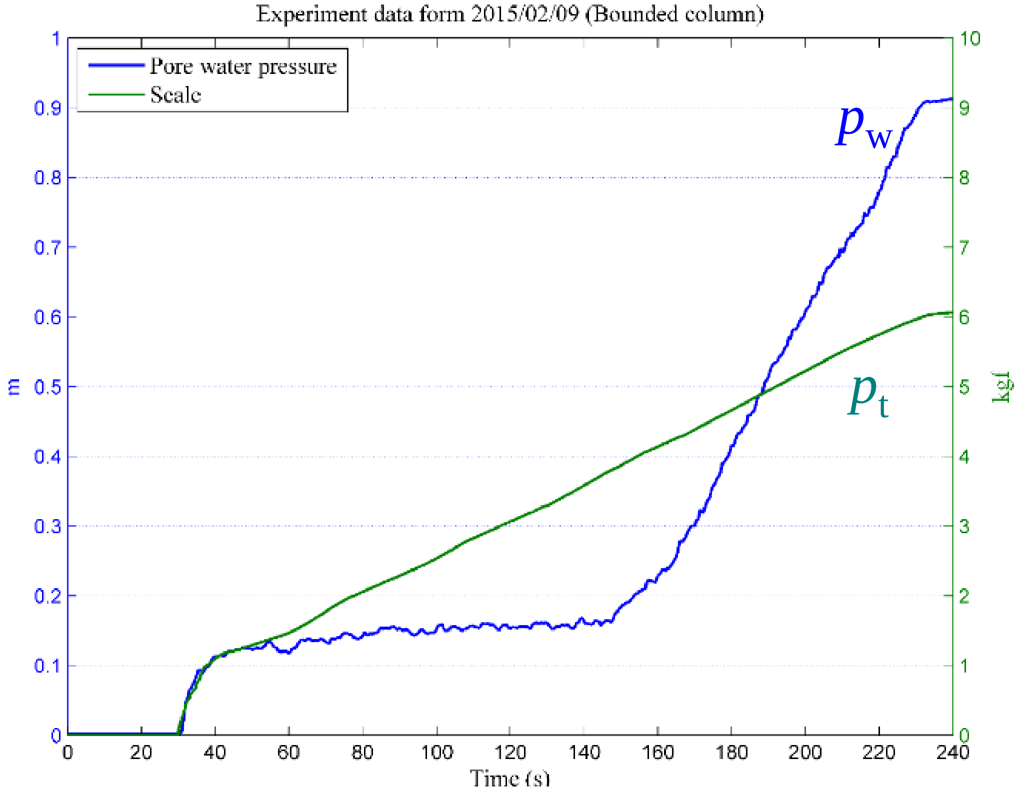


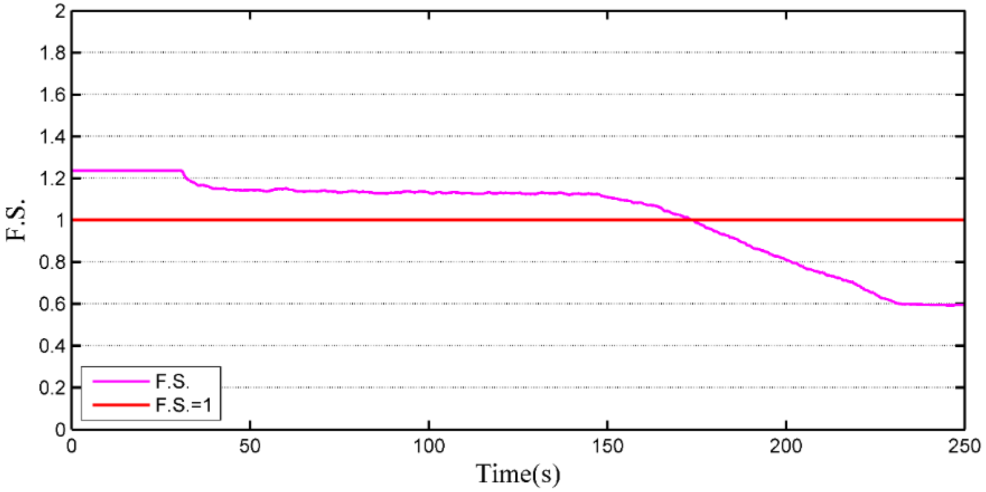
Case III: Air escape from top



$$\text{S.F.}=\frac{c+\{(1-n)\gamma_s L_s+Sn\gamma_w h(t)-p_w(t)\}\tan\varphi\cos\theta}{\{(1-n)\gamma_s L_s+Sn\gamma_w h(t)\}\sin\theta}$$

where, $\varphi=25^\circ;\theta=30^\circ;c=0.$





- Develop the theory from physical phenomenon

Equation of mass conservation

$$\frac{\partial nS\rho_w}{\partial t} + \nabla \cdot nS\rho_w \boldsymbol{v}_w = 0$$

$$\frac{\partial n(1-S)\rho_a}{\partial t} + \nabla \cdot n(1-S)\rho_a \boldsymbol{v}_a = 0$$

Equation of momentum conservation

$$nS\rho_w \frac{D\boldsymbol{v}_w}{Dt} = nS\rho_w \boldsymbol{g} + \nabla \cdot (-p_w \boldsymbol{I}) + \boldsymbol{f}_w$$

$$n(1-S)\rho_a \frac{D\boldsymbol{v}_a}{Dt} = n(1-S)\rho_a \boldsymbol{g} + \nabla \cdot (-p_a \boldsymbol{I}) + \boldsymbol{f}_a$$

$$(1-n)\rho_s \frac{D\boldsymbol{v}_s}{Dt} = (1-n)\rho_s \boldsymbol{g} + \nabla \cdot \boldsymbol{\sigma}_s^* + \boldsymbol{f}_s$$

Interaction among the constituents

$$\boldsymbol{f}_w + \boldsymbol{f}_s + \boldsymbol{f}_a = 0$$

Equation of state

$$p_a V = \frac{m}{M} \bar{R} T$$

- Convert the 3-D governing equation into 1-D.

- Interaction among the constituents in 1-D

-the momentum supplies(interactions) can be divided into two parts

f^{buoy}: caused by the normal pressure in the constituents surface

f^{rel}: the drag force due to the relative velocity tangential to the constituents surface

$$\overbrace{f_{\mathrm{w}}^{\text{buoy}} = (1-n)\frac{nS}{n}\frac{\partial p_{\mathrm{w}}}{\partial z} + \frac{n(1-S)}{n}\frac{\partial p_{\mathrm{w}}}{\partial z} \qquad f_{\mathrm{w}}^{\text{rel}} = -nS\frac{\partial p_{\mathrm{iw}}}{\partial z}}^{f_{\mathrm{w}}}$$

$$\overbrace{f_{\mathrm{s}}^{\text{buoy}} = -\left\{(1-n)\frac{nS}{n}\frac{\partial p_{\mathrm{w}}}{\partial z} + (1-n)\frac{n(1-S)}{n}\frac{\partial p_{\mathrm{a}}}{\partial z}\right\} \qquad f_{\mathrm{s}}^{\text{rel}} = nS\frac{\partial p_{\mathrm{iw}}}{\partial z} + n(1-S)\frac{\partial p_{\mathrm{ia}}}{\partial z}}^{f_{\mathrm{s}}}$$

$$\overbrace{f_{\mathrm{a}}^{\text{buoy}} = (1-n)\frac{n(1-S)}{n}\frac{\partial p_{\mathrm{a}}}{\partial z} - \frac{n(1-S)}{n}\frac{\partial p_{\mathrm{w}}}{\partial z} \qquad f_{\mathrm{a}}^{\text{rel}} = -n(1-S)\frac{\partial p_{\mathrm{ia}}}{\partial z}}^{f_{\mathrm{a}}}$$

- Governing equation in 1-D form

Equation of mass conservation

$$\frac{\partial}{\partial t}\left(nS\rho_{\mathrm{w}}\right)+\frac{\partial}{\partial z}\left(nS\rho_{\mathrm{w}}u_{\mathrm{w}}\right)=0$$

$$\frac{\partial}{\partial t}\left\{n\left(1-S\right)\rho_{\mathrm{a}}\right\}+\frac{\partial}{\partial z}\left\{n\left(1-S\right)\rho_{\mathrm{a}}u_{\mathrm{a}}\right\}=0$$

Equation of momentum conservation

$$nS\rho_{\mathrm{w}}\frac{Du_{\mathrm{w}}}{Dt}=-nS\rho_{\mathrm{w}}g-nS\left(\frac{\partial p_{\mathrm{w}}}{\partial z}+\frac{\partial p_{\mathrm{iw}}}{\partial z}\right)$$

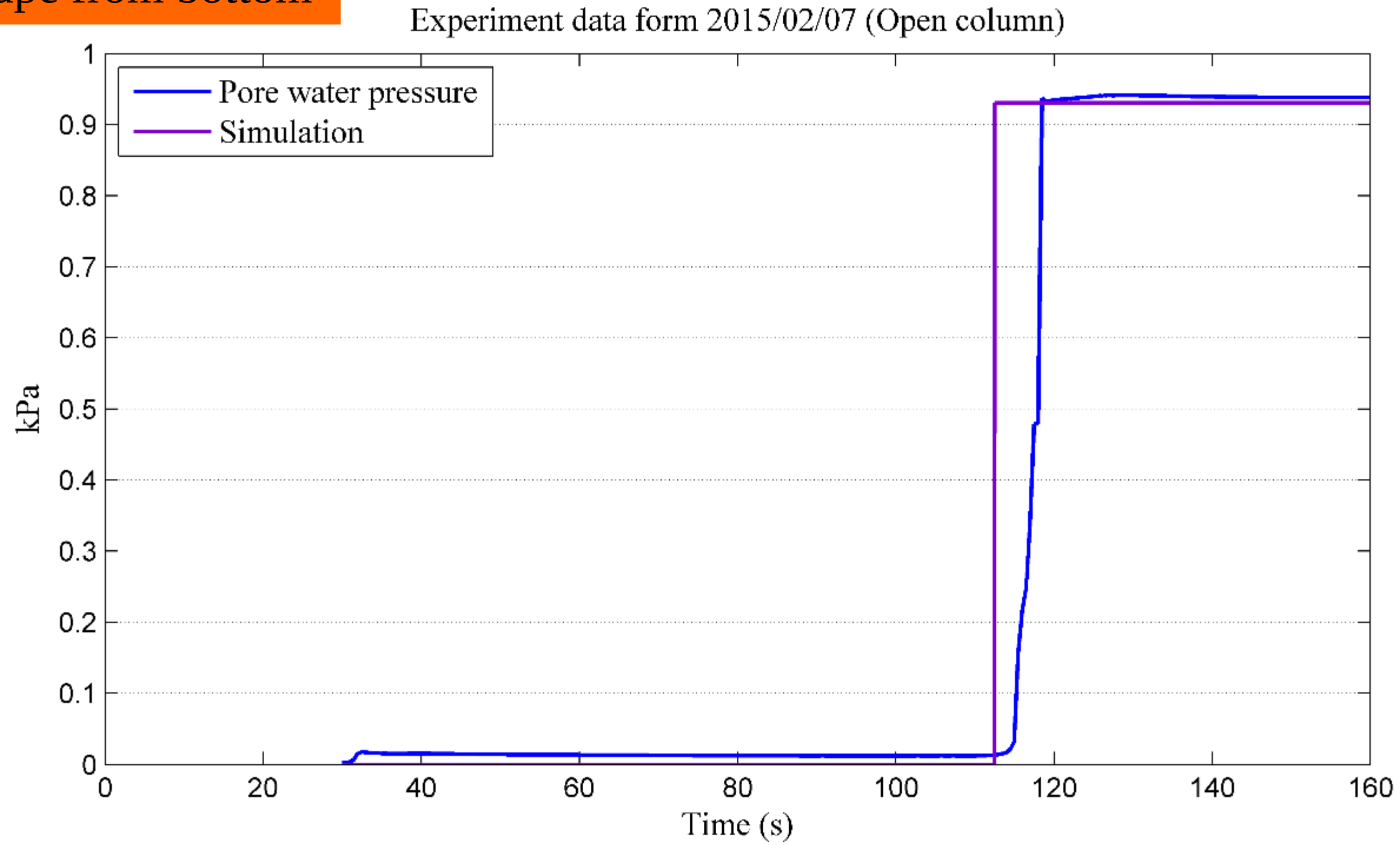
$$n(1-S)\rho_{\mathrm{a}}\frac{Du_{\mathrm{a}}}{Dt}=-n(1-S)\rho_{\mathrm{a}}g+\left(nS-S-n\right)\frac{\partial p_{\mathrm{a}}}{\partial z}-\left(1-S\right)\frac{\partial p_{\mathrm{w}}}{\partial z}-n\left(1-S\right)\frac{\partial p_{\mathrm{ia}}}{\partial z}$$

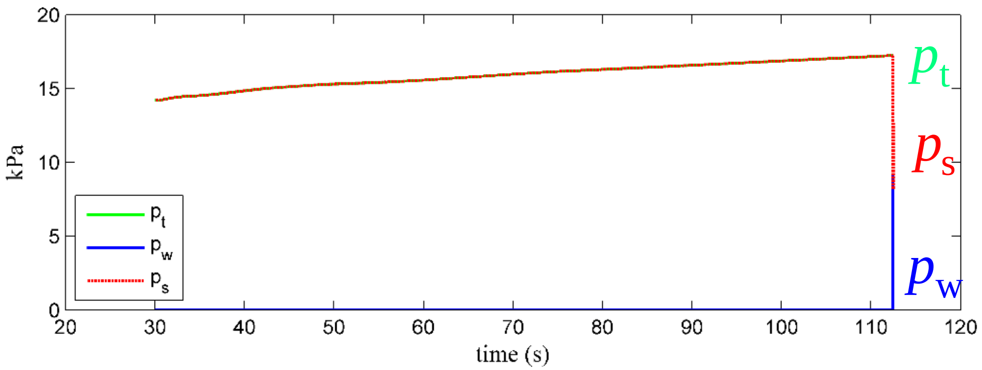
$$(1-n)\rho_{\mathrm{s}}\frac{Du_{\mathrm{s}}}{Dt}=-(1-n)\rho_{\mathrm{s}}g-\frac{\partial p_{\mathrm{s}}}{\partial z}+S\left\{n\frac{\partial p_{\mathrm{iw}}}{\partial z}-\left(1-n\right)\frac{\partial p_{\mathrm{w}}}{\partial z}\right\}+\left(1-S\right)\left\{n\frac{\partial p_{\mathrm{ia}}}{\partial z}-\left(1-n\right)\frac{\partial p_{\mathrm{a}}}{\partial z}\right\}$$

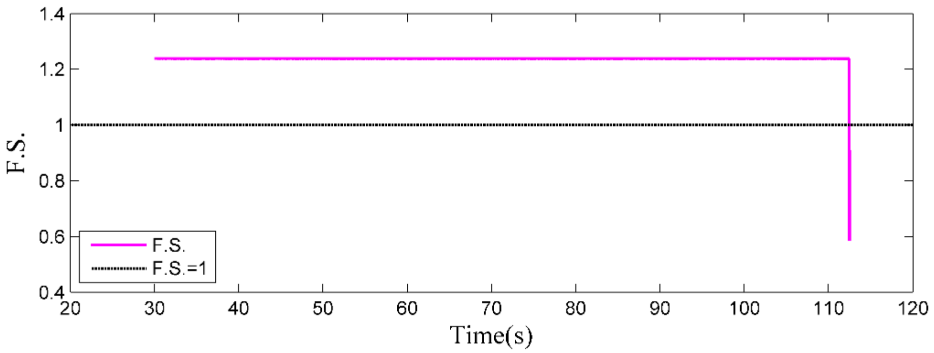
Equation of state

$$p_{\mathrm{a}}zA=\frac{m}{M}\bar{R}T$$

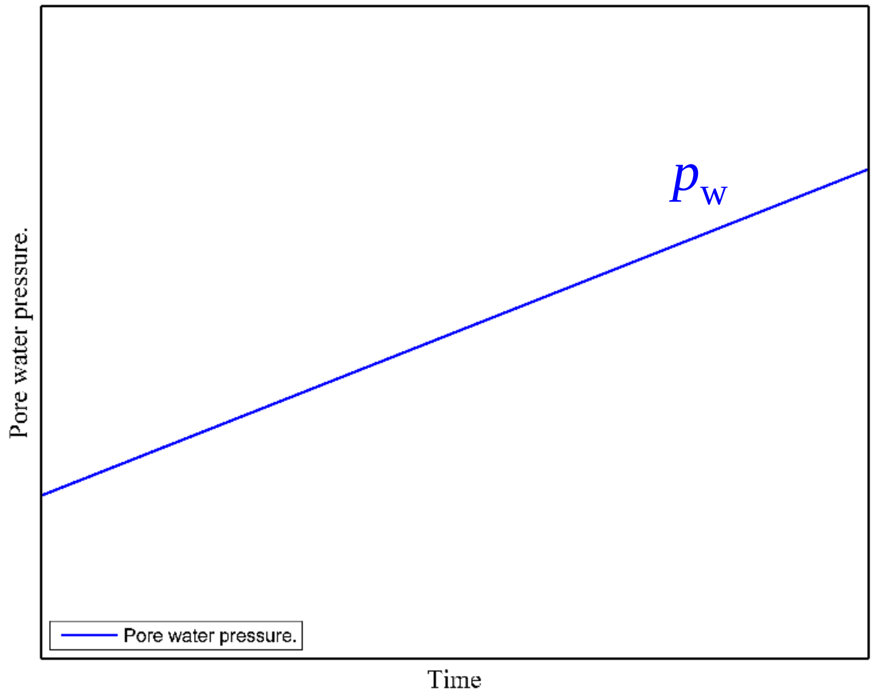
Case I: Air escape from bottom

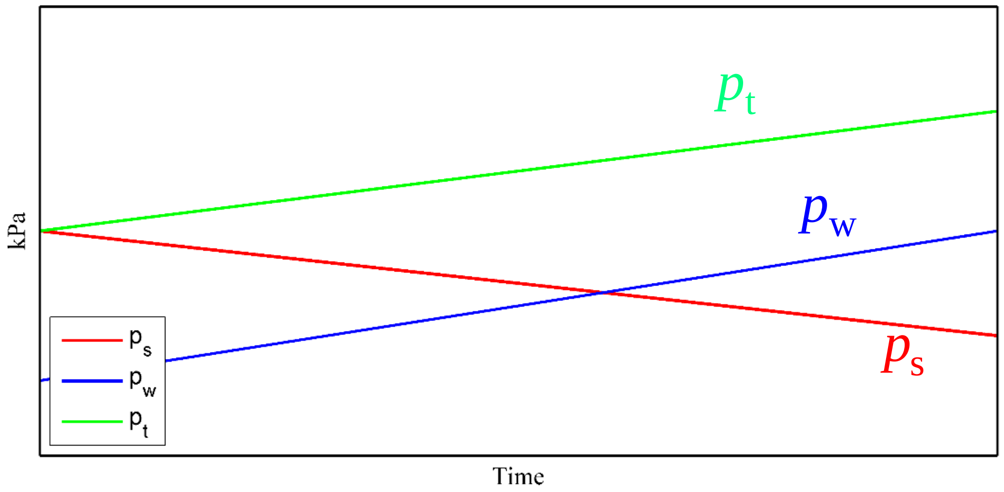


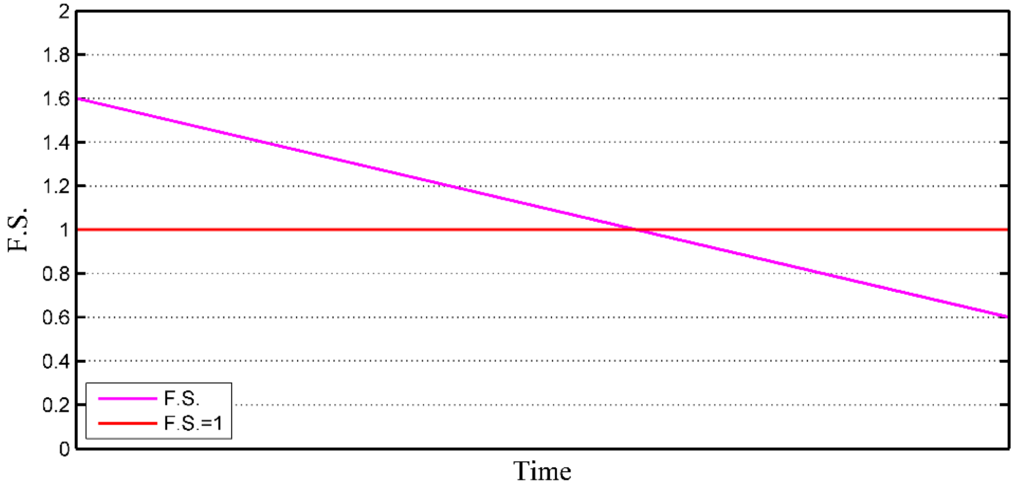




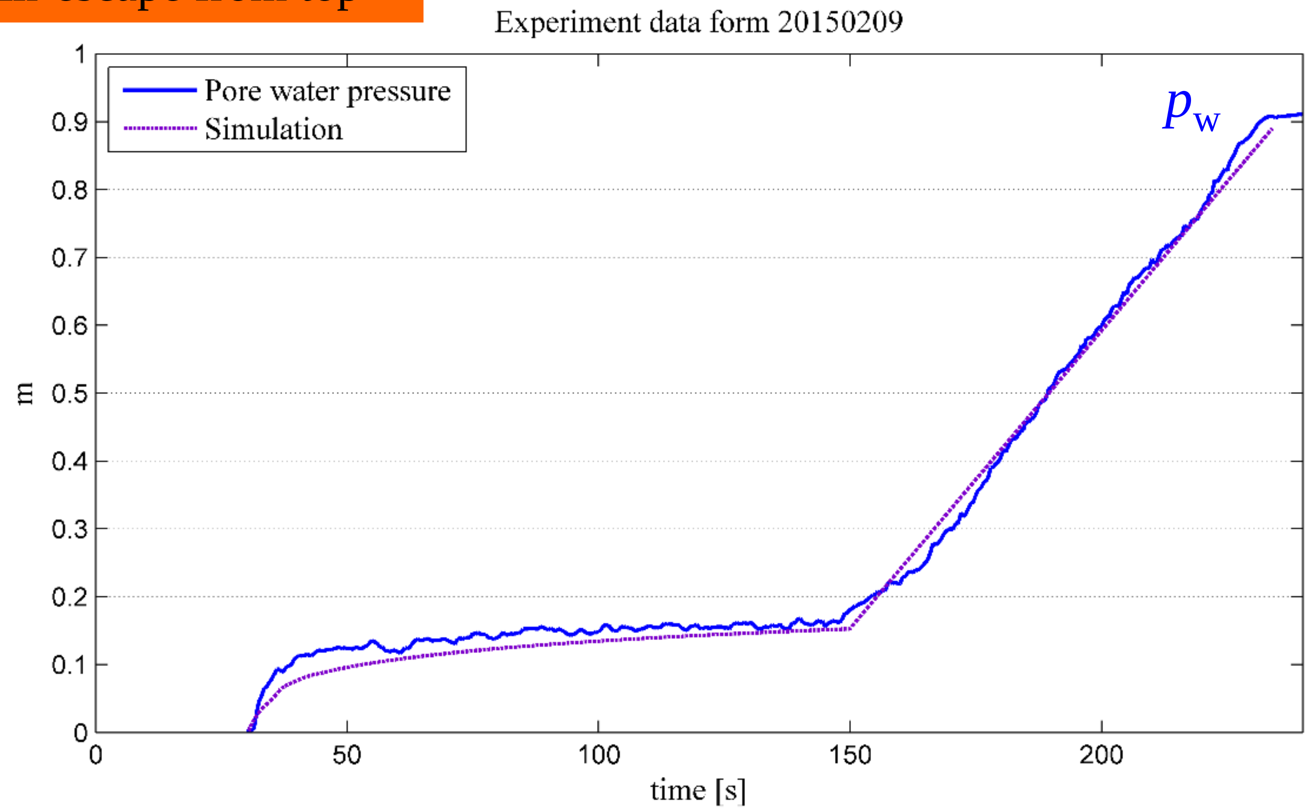
Case II: Groundwater upwelling

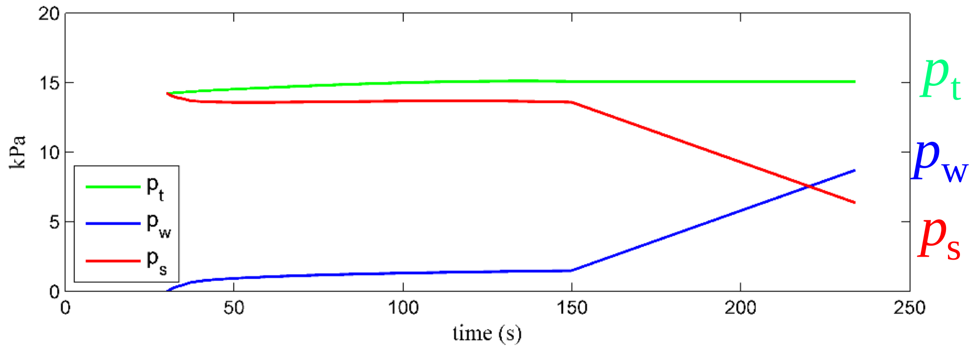


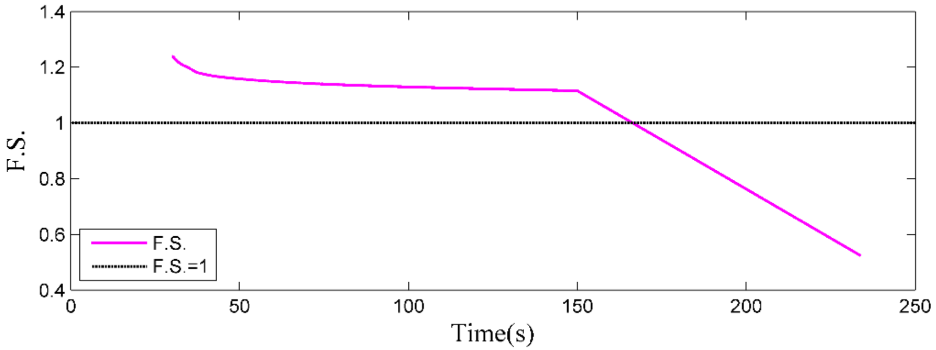




Case III: Air escape from top







Conclusion

- This model is a pilot study of LSL warning system in Taiwan . More field data are necessary before it is used.

- The moment of infiltration front touch with groundwater will induce fast-moving LSL.

Don't Touch !!


PP.FALOO.COM飞卢美图
E.T.
THE EXTRA-TERRESTRIAL
THE 20TH ANNIVERSARY