Landslide Dam Formation

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Outline

- Introduction
- Formation mechanism
- Geometry of a landslide dam
- Conclusions

Introduction

What is landslide dam ?

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The Definition of landslide dam

In addition to steep terrain, torrential river, loose soil material, and fragile geologic conditions, typhoon and extreme rainfall events cause frequent land collapse, landslide, and debris flow events. These events may result in landslide dams.

Landslide mass moves to the river channel and block the flow, the mass can be called the landslide dam.

The water is stored behind the dam and forms a lake, the lake can be called the landslide-dammed lake.

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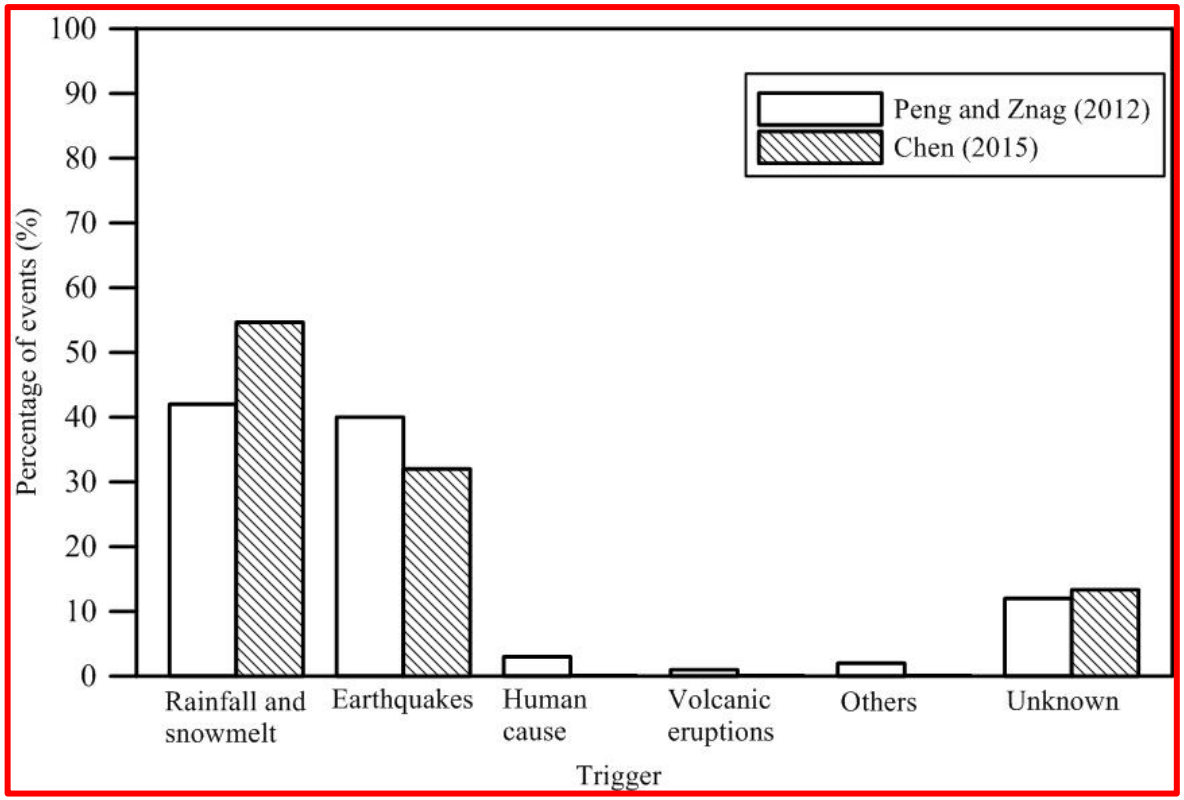
Causes of landslide dam

Earthquakes and rainfall often occur in Taiwan, if earthquakes and rainfall induced avalanches, landslides or debris flows, the material blocked river will form landslide dams.

In 1999, the Chi-Chi Earthquake caused 13 dams in Taiwan.

Typhoon Morakot stroke southern Taiwan between 8/6/2009 and 8/9/2009 and caused 17 dams.

In 2008, The Wenchuan Earthquake caused 256 dams in China.



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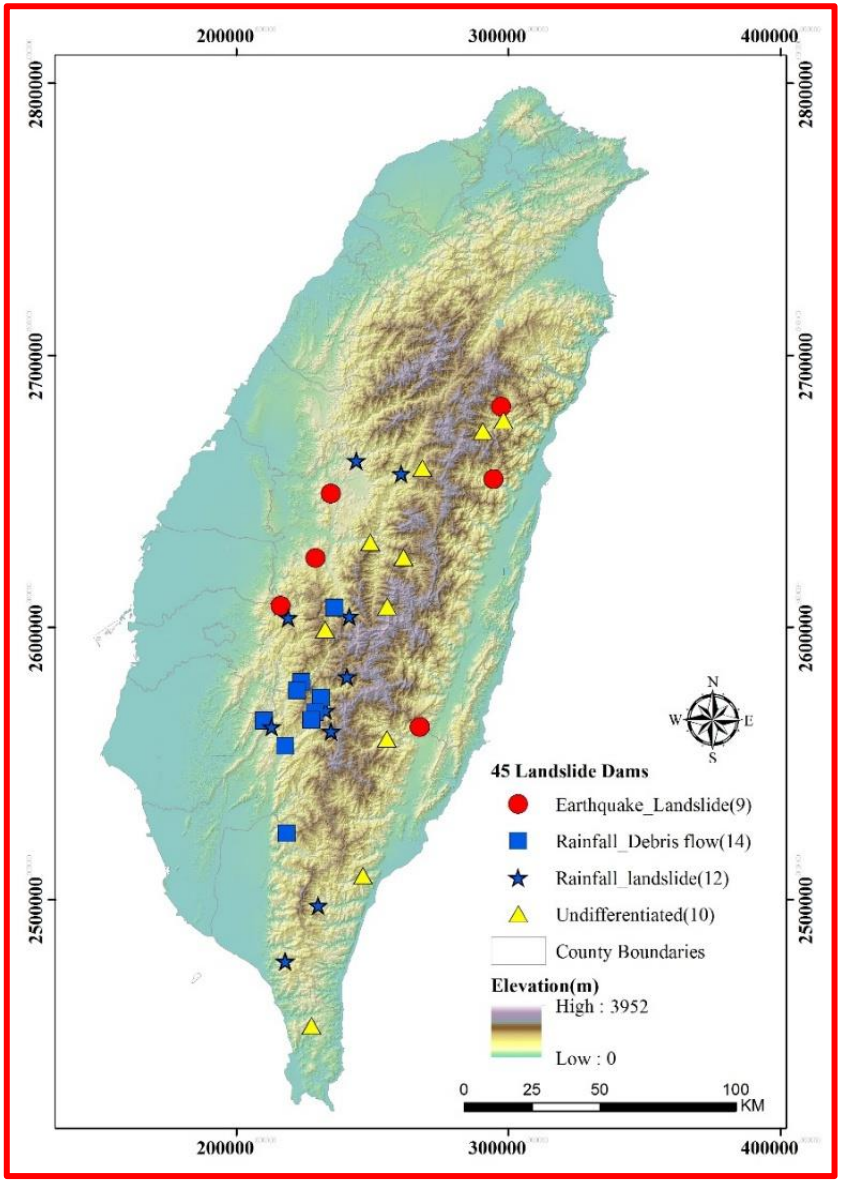
Causes of landslide dam

Figure illustrates the coordinate data distribution of **45 landslide dams** in Taiwan.

The triggering causes of landslide dam via **earthquake** or **typhoon event** are similar to many cases throughout the world.



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The hazards of landslide dam

Multiple landslide dams may form within a mountainous area and pose an additional potential danger to the region.

When a landslide dam suddenly fails, the material of the dam and the river flow rapidly transport to downstream. The momentum of the flow can cause serious damages.

The formation of landslide dams occurs over a short time, and often causes large disasters that are sudden and may have a high impact over a large area, thus seriously threatening lives and properties both upstream and downstream.

Therefore, we must understand the mechanism of its formation, and further improve the countermeasures of disaster prevention and mitigation.

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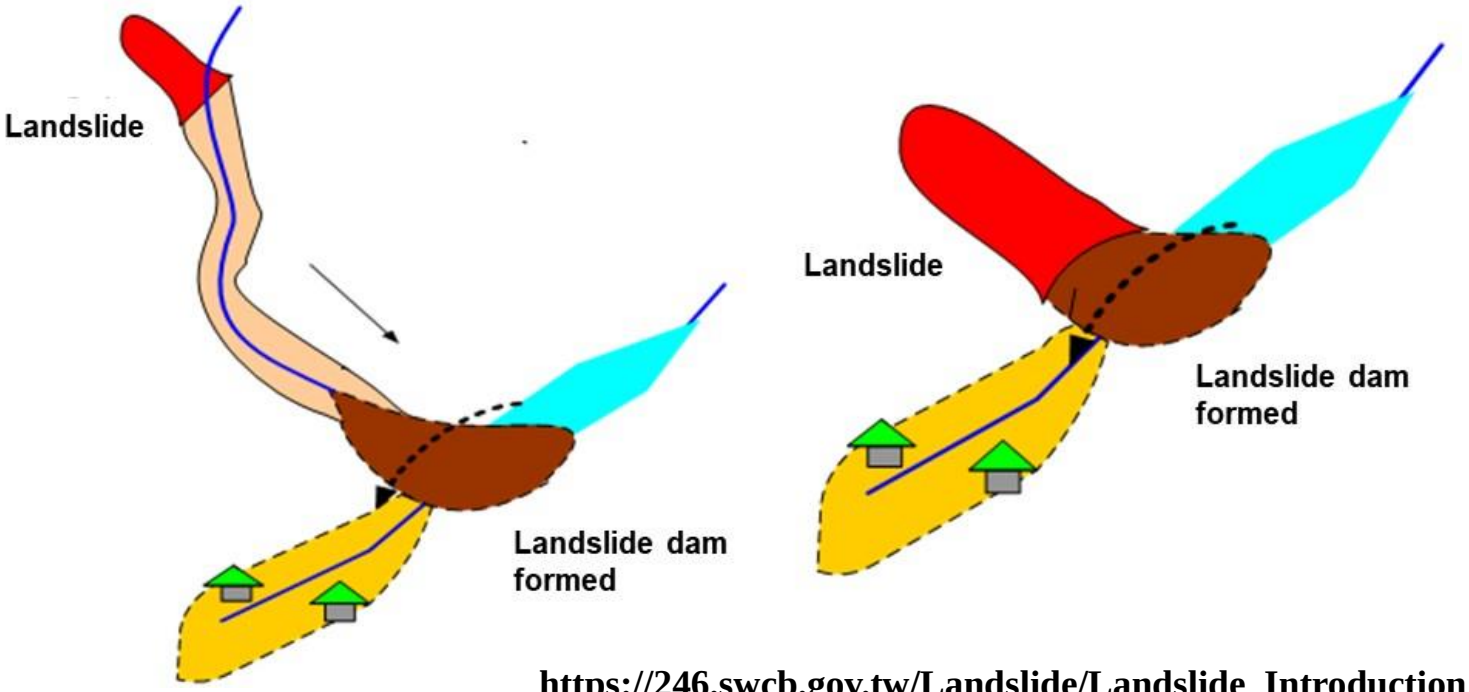
Formation mechanism

Formation mechanism of landslide dam

- **The formation mechanisms of landslide dam are mainly divided into two parts:**
  - **Landslide masses are transformed into a debris flow to form a natural dam.**
  - **Landslide masses directly to be a natural dam.**



https://246.swcb.gov.tw/Landslide/Landslide_Introduction

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Formation mechanism of landslide dam

Photos provided by DPRC, NCKU

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Formation conditions of landslide dam

Photos provided by DPRC, NCKU

- **Is it possible to know the location of landslide dam in advance?**

1. **the runout of the landslide debris needs to traverse the width of the stream or river**
2. **the thickness of the landslide debris in the stream or river must be greater than the water depth**
3. **the depositional capacity of the landslide must be higher than the erosive capacity of the river**

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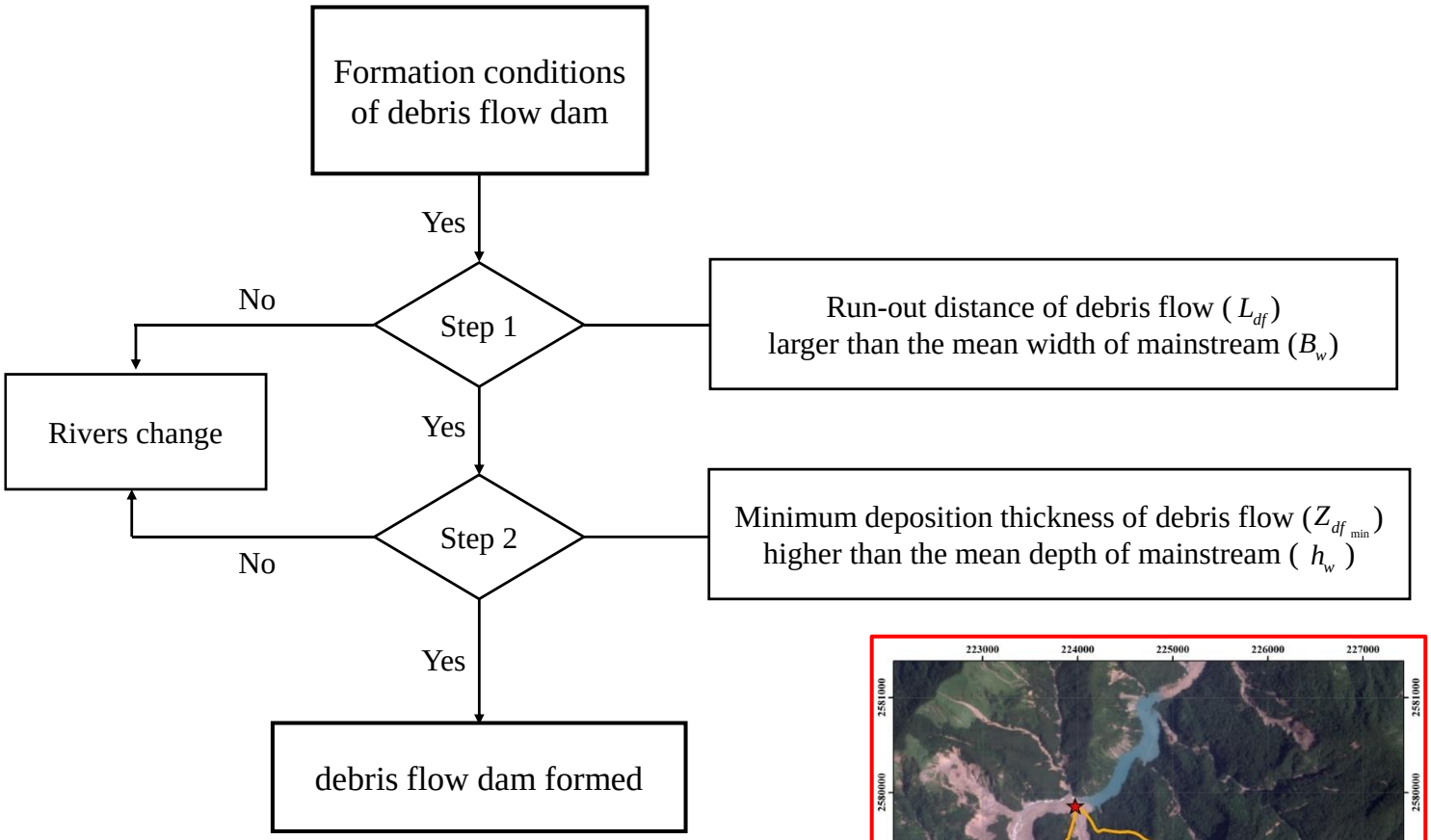
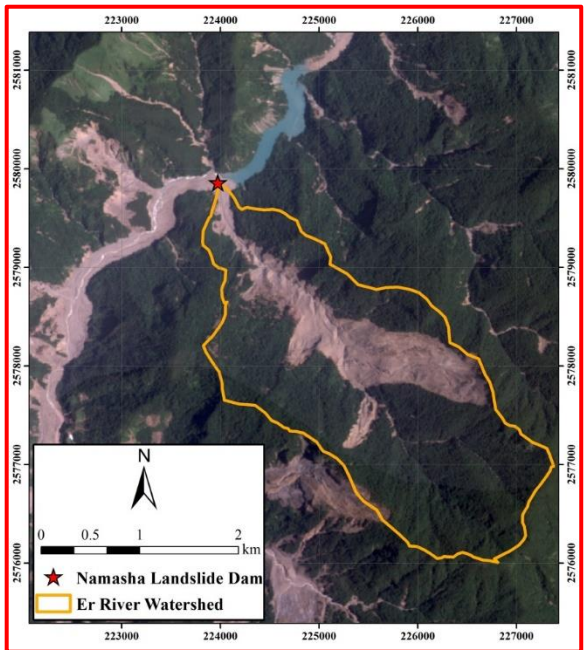
Formation of dam by debris flow





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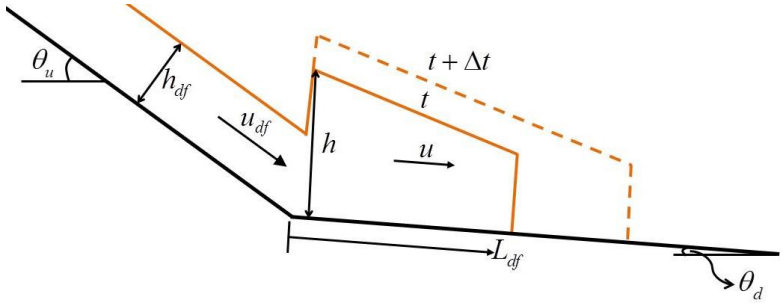
Run out distance of debris flow

$$L_{df} > B_w$$

$$L_{df} = \frac{U^2}{G}$$



$$U = u_{df}\cos(\theta_u - \theta_d)\left\{1 + \frac{\left[(\sigma-\rho)C_{df}K_a + \rho\right]\cos\theta_u}{2\left[(\sigma-\rho)C_{df} + \rho\right]}\frac{gh_{df}}{{u_{df}}^2}\right\}$$ **Takahashi (1977)**

$$G = \frac{(\sigma-\rho)gC_{df}\cos\theta_d\tan\phi_k}{(\sigma-\rho)C_{df} + \rho} - g\sin\theta_d$$ **Takahashi (1977)**

$$C_{df\infty} \equiv C_{df} = \frac{\rho\tan\theta_u}{(\sigma-\rho)(\tan\phi_{df} - \tan\theta_u)}$$ **Takahashi (1977)**

$$u_{df} = \frac{2}{5d_{50}}\left\{\frac{g\sin\theta_u}{a\sin\phi_k}\left[C_{df} + (1-C_{df})\frac{\rho}{\sigma}\right]\right\}^{\frac{1}{2}}\left[\left(\frac{C_*}{C_{df}}\right)^{\frac{1}{3}} - 1\right]{h_{df}}^{\frac{3}{2}}$$ **Takahashi (1974)**

$$Q_{df} = \frac{1}{360}\frac{C_*}{C_* - C_{df}}CIA_{df}$$ **Tsai (2006)**

$$Q_{df} = B_u q_{df} = B_u h_{df} u_{df}$$ **Tsai (2006)**

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Thickness of debris flow and water depth

$Z_{df_{\min}} > h_w$

$$Z_{df_{\max}} = L_{df} \tan\left(\theta_{df} - \theta_d\right)$$

$$Z_{df_{\min}} = \left(L_{df} - B_w\right) \times \tan\left(\theta_{df} - \theta_d\right)$$

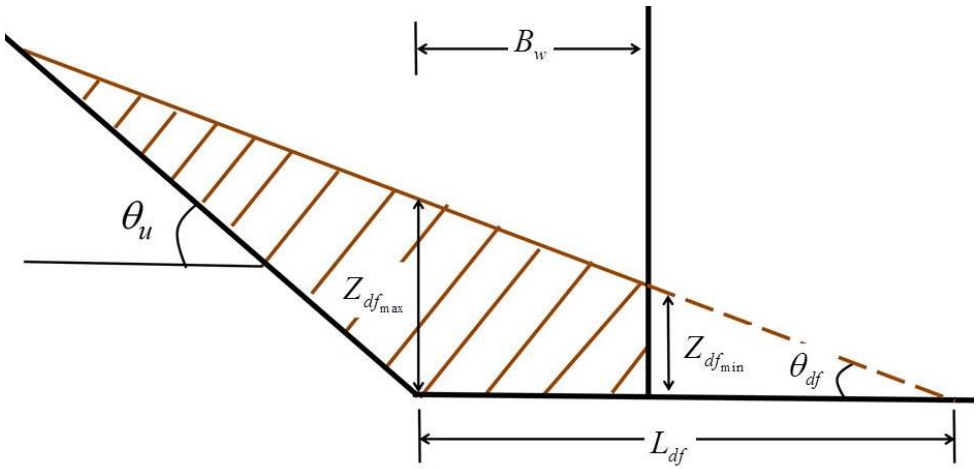
Tsai et al. (2006)

$$\tan\theta_{df} = \frac{C_*\left(\sigma-\rho\right)\tan\phi_{df}}{C_*\left(\sigma-\rho\right)+\rho\left[1+4.5\times10^{-4}C_{df}{}^{-6}\left(\frac{q_{df}{}^2}{gd_{50}{}^3}\right)^{\frac{1}{3}}\right]}$$

Tsai et al. (2006)

$$Q_w = \frac{A_w}{A_{w1}} Q_{w1}$$

$$Q_w = \frac{1}{n}\frac{\left(B_w h_w\right)^{\frac{5}{3}}}{\left(B_w + 2h_w\right)^{\frac{2}{3}}}\theta_w{}^{\frac{1}{2}}$$



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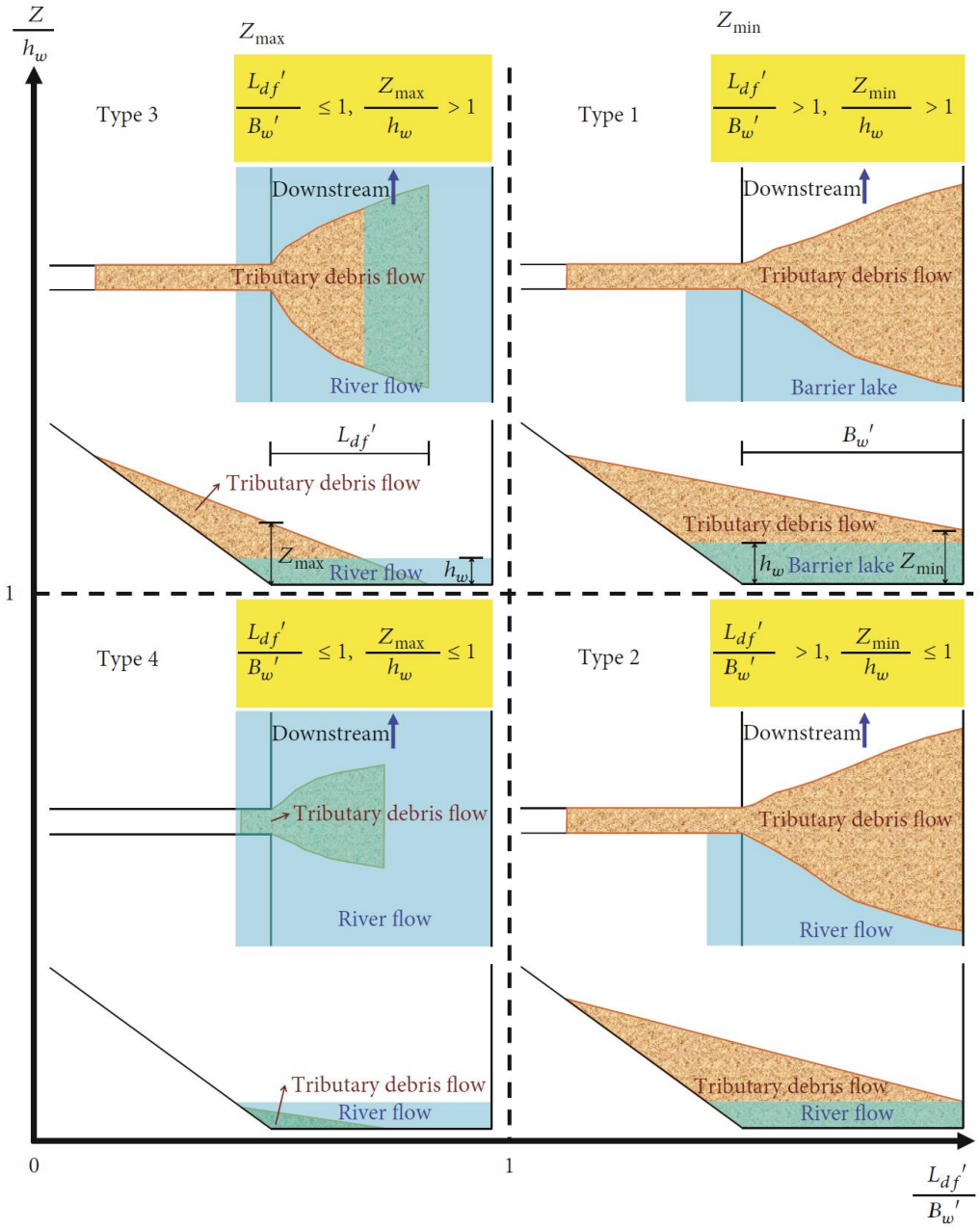
Scenarios of debris flow deposition



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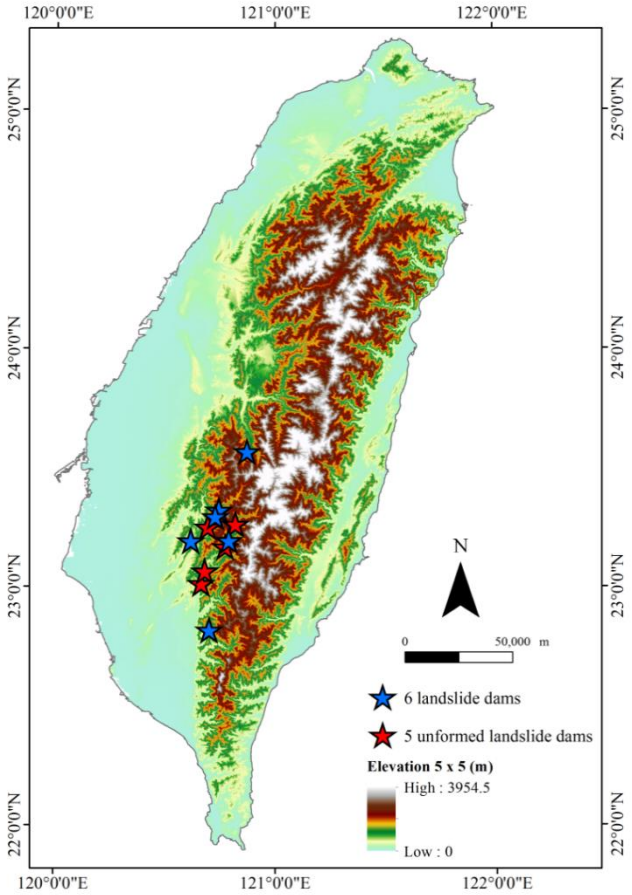
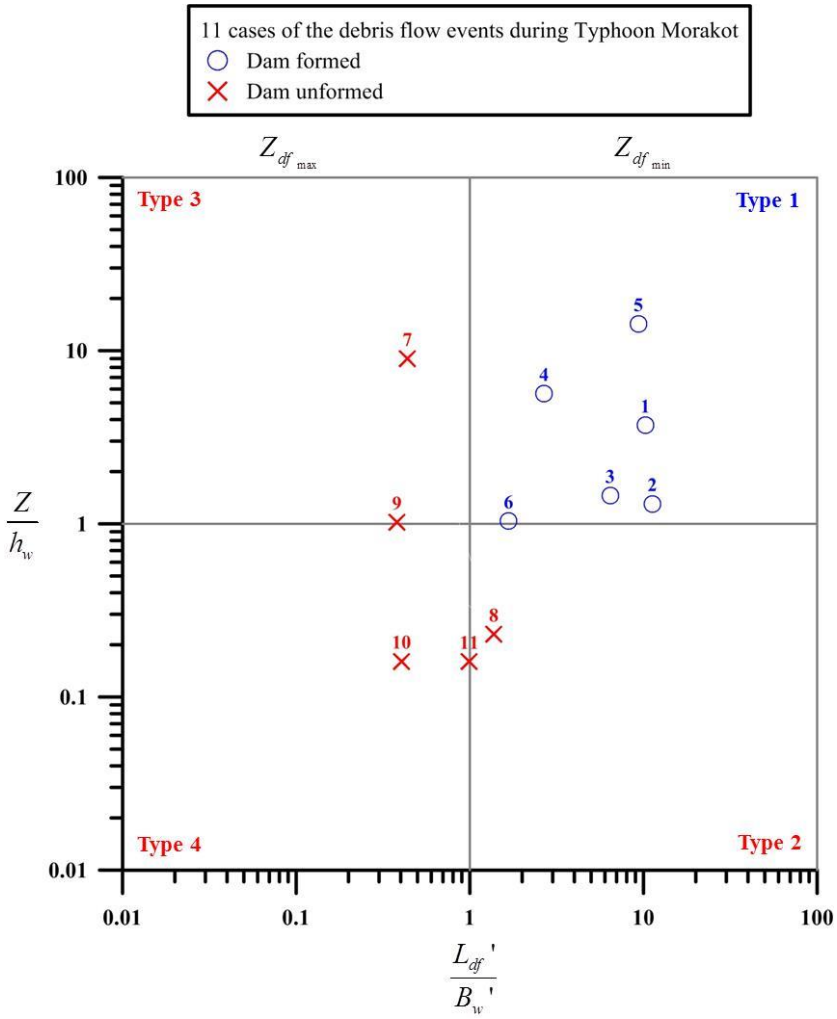
Case study of debris flow dam in Taiwan





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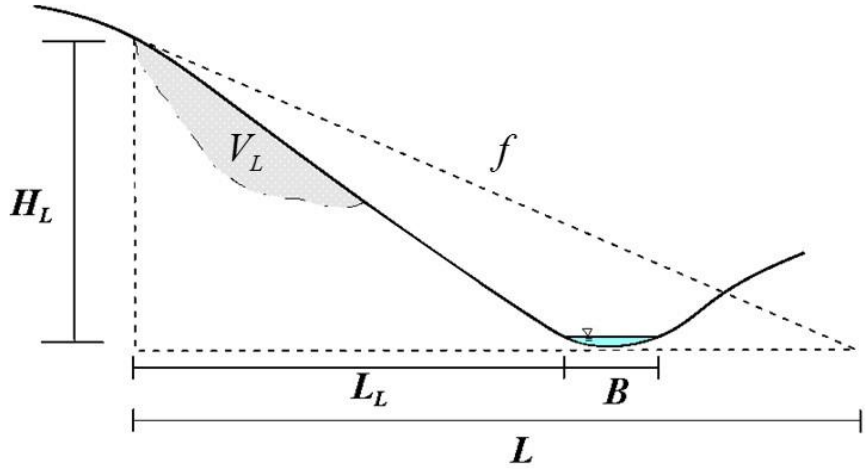
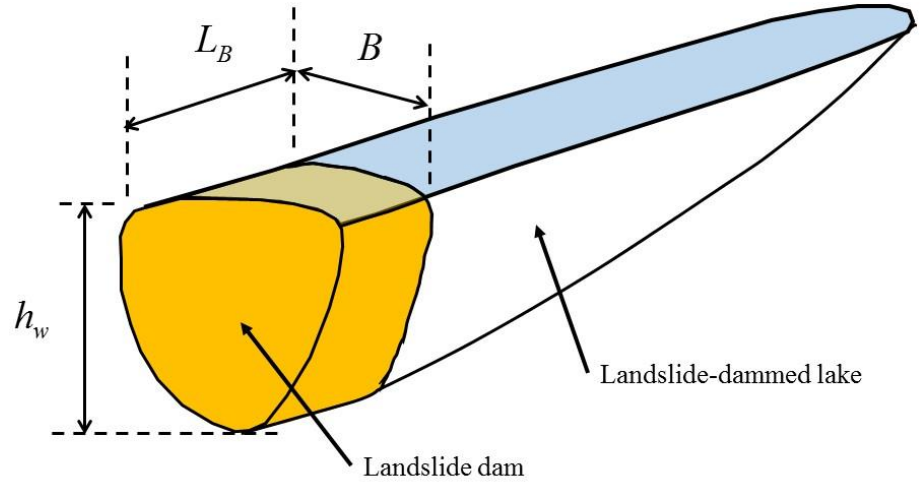
Formation of dam by landslide

1. Run out distance of landslide



Heim (1932)

2. Thickness of landslide and water depth



Tabata et al. (2002)

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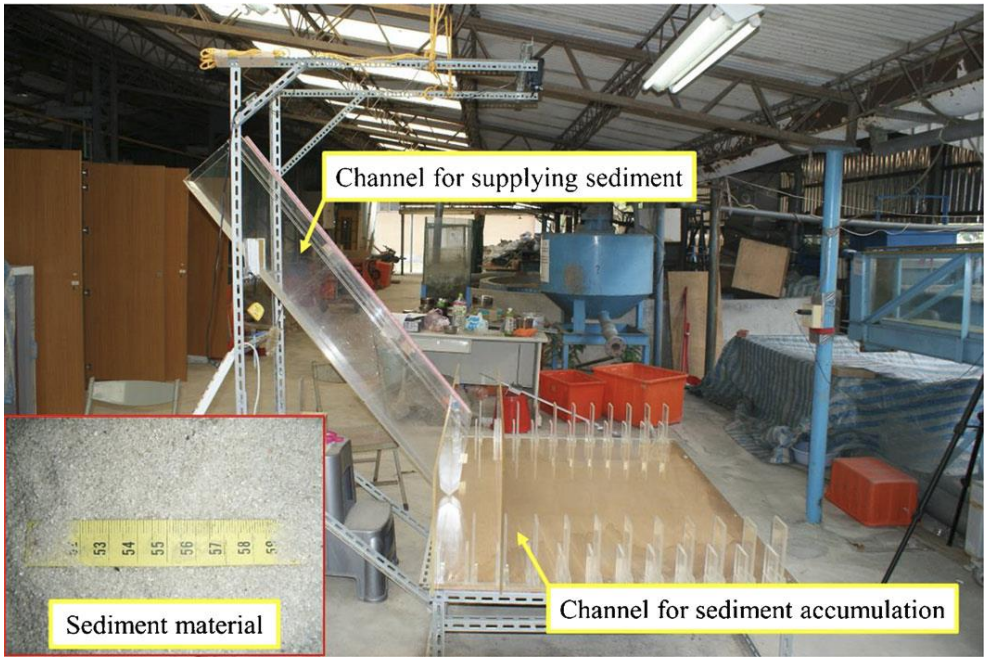
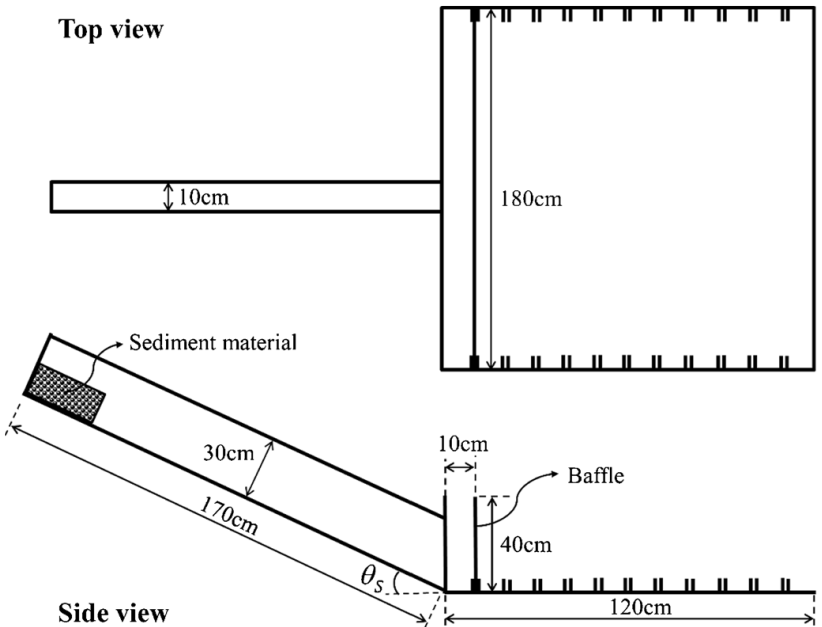
laboratory experiments of landslide dam





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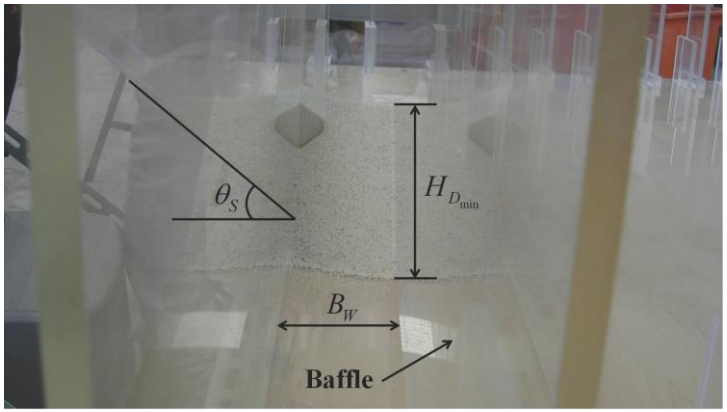

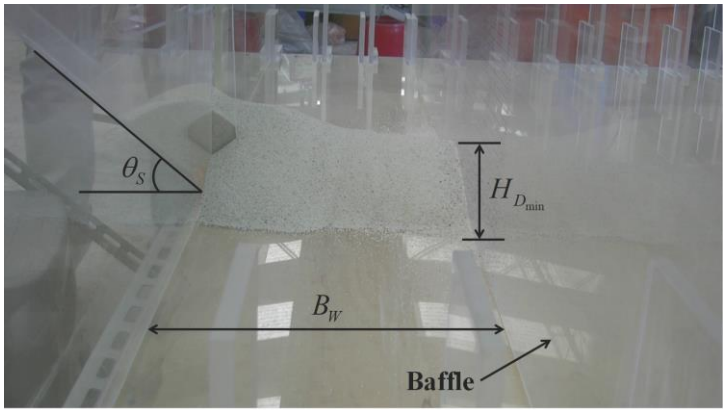

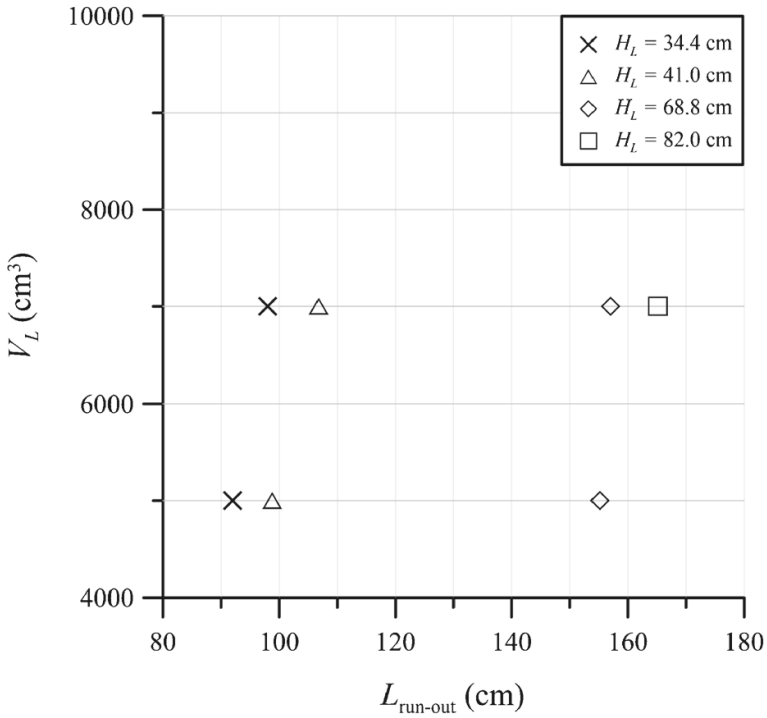

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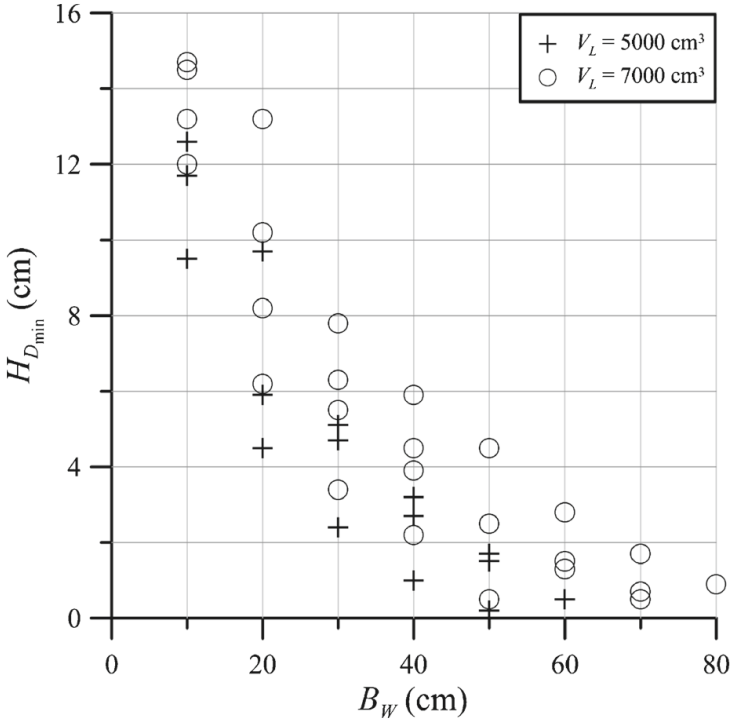

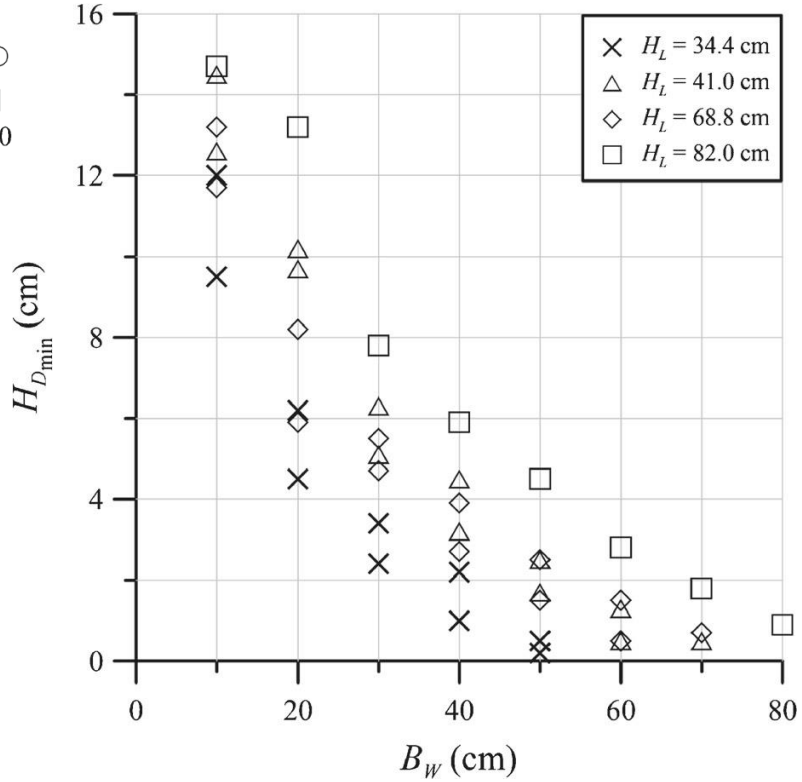

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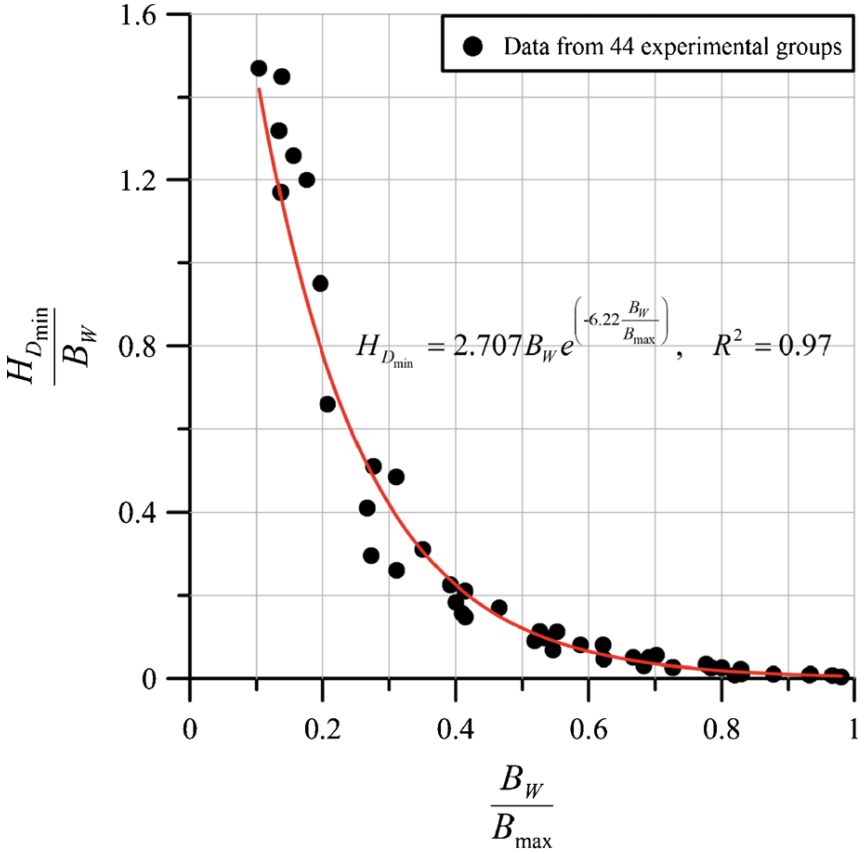
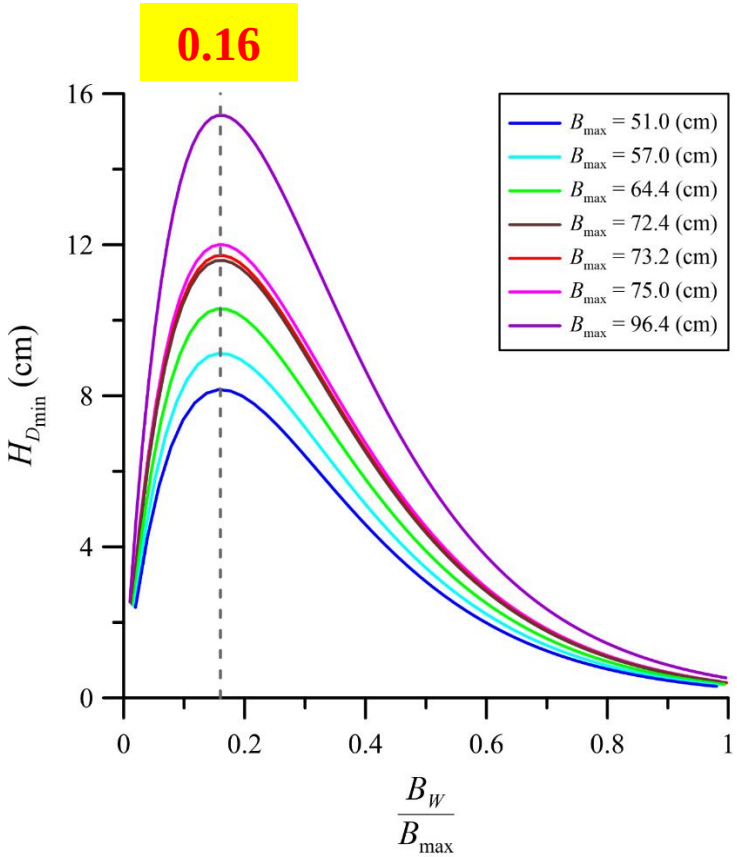
Dimensionless analysis

$\frac{H_{D_{\min}}}{B_W}$ and $\frac{B_W}{B_{\max}}$, when $\frac{B_W}{B_{\max}} > 1$, the minimum height is **0**.





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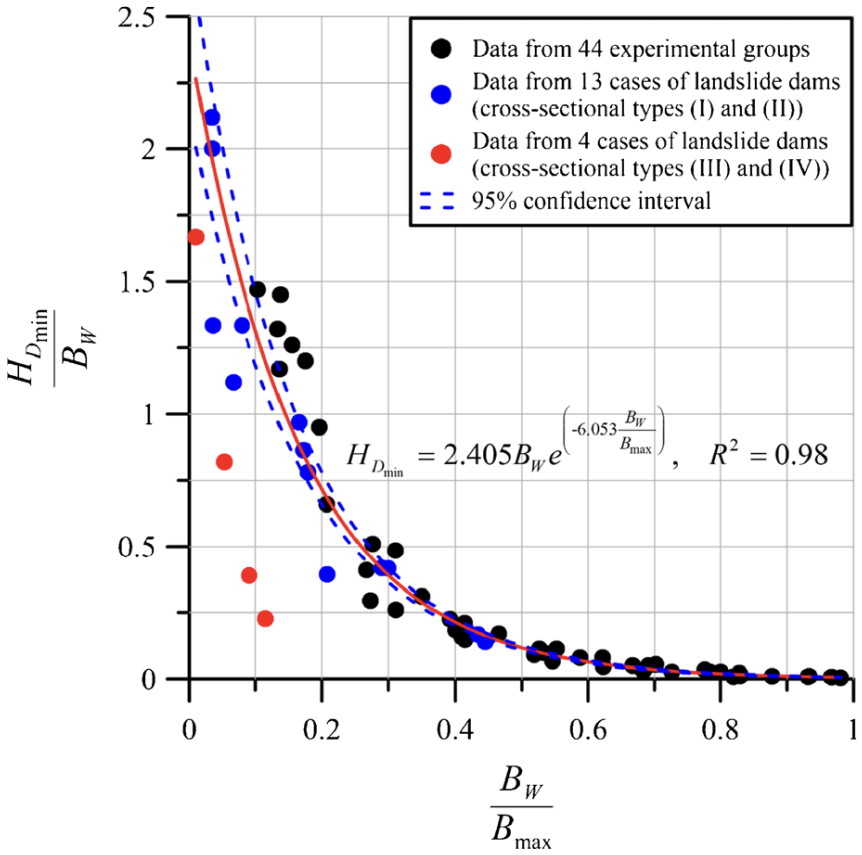
Photos provided by DPRC, NCKU



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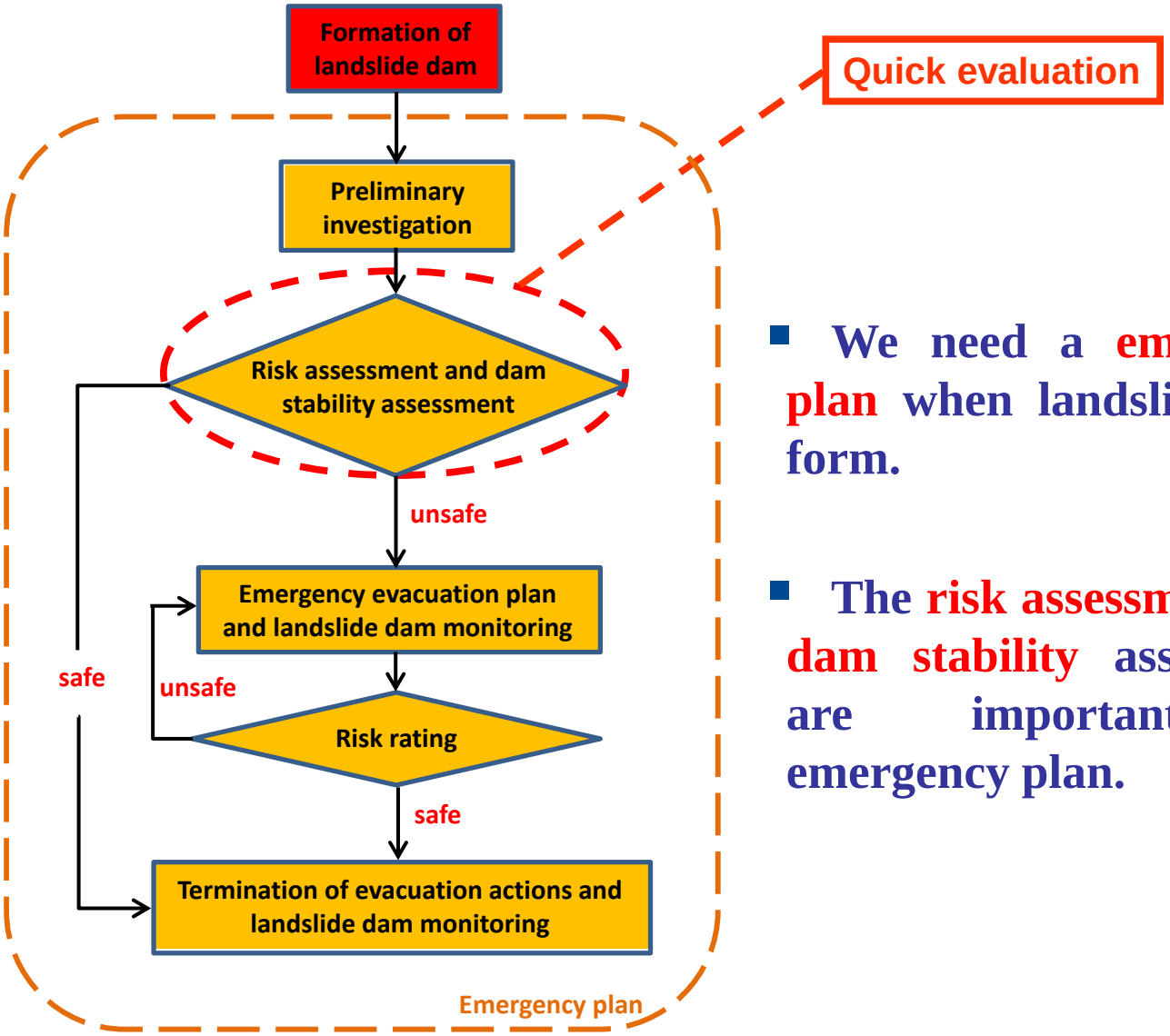
Geometry of a landslide dam

The geometry parameters of landslide dam



- We need a emergency plan when landslide dam form.
- The risk assessment and dam stability assessment are important in emergency plan.

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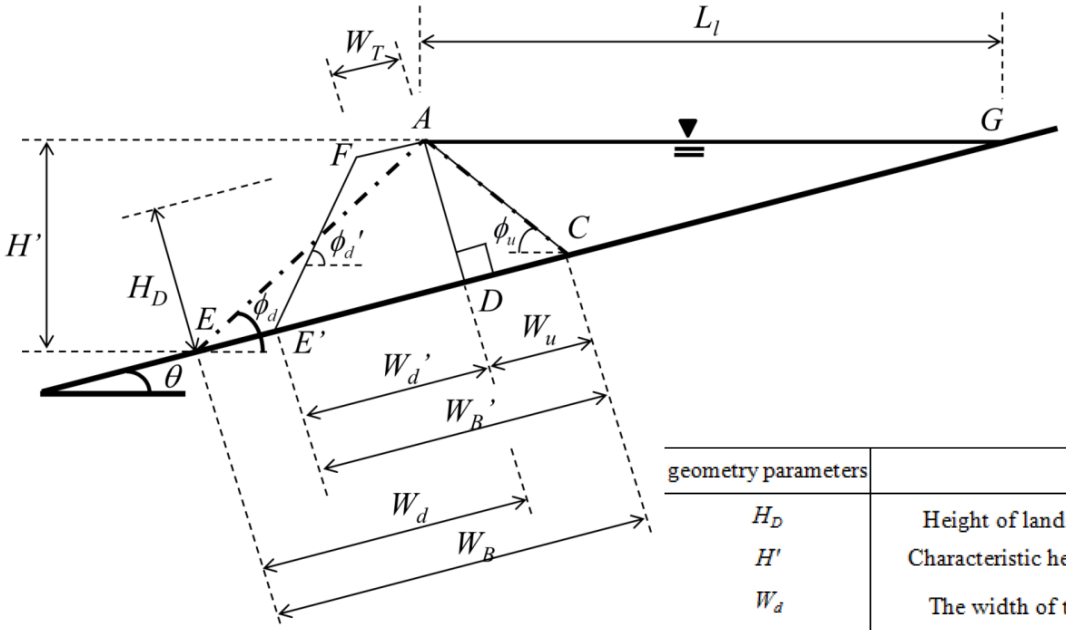
The geometry parameters of landslide dam



geometry parameters	Definitions
H_D	Height of landslide dam, from river bed to overflow point, $\overline{AD}$
H'	Characteristic height of dam, from toe of the dam to overflow point
W_d	The width of the triangular dam in downstream direction, $\overline{ED}$
W_d'	The width of the trapezoidal dam in downstream direction, $\overline{E'D}$
W_u	The width of the triangular and trapezoidal dam in upstream direction, $\overline{DC}$
W_B	The width of the triangular dam bottom, $\overline{EC}$
W_B'	The width of the trapezoidal dam bottom, $\overline{E'C}$
W_T	The width of the trapezoidal dam top, $\overline{FA}$
L_l	Maximum length of landslide-dammed lake, $\overline{AG}$
θ	River bed slope
ϕ_u	The angle of the triangular and trapezoidal dam in upstream direction
ϕ_d	The angle of the triangular dam in downstream direction
ϕ_d'	The angle of the trapezoidal dam in downstream direction
$\triangle ACE$	The area of the triangular dam
$\square ACE'F$	The area of the trapezoidal dam

Chen et al. (2014)

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The establishment process of geometry assessment model

Rapid Geometry Assessment Method

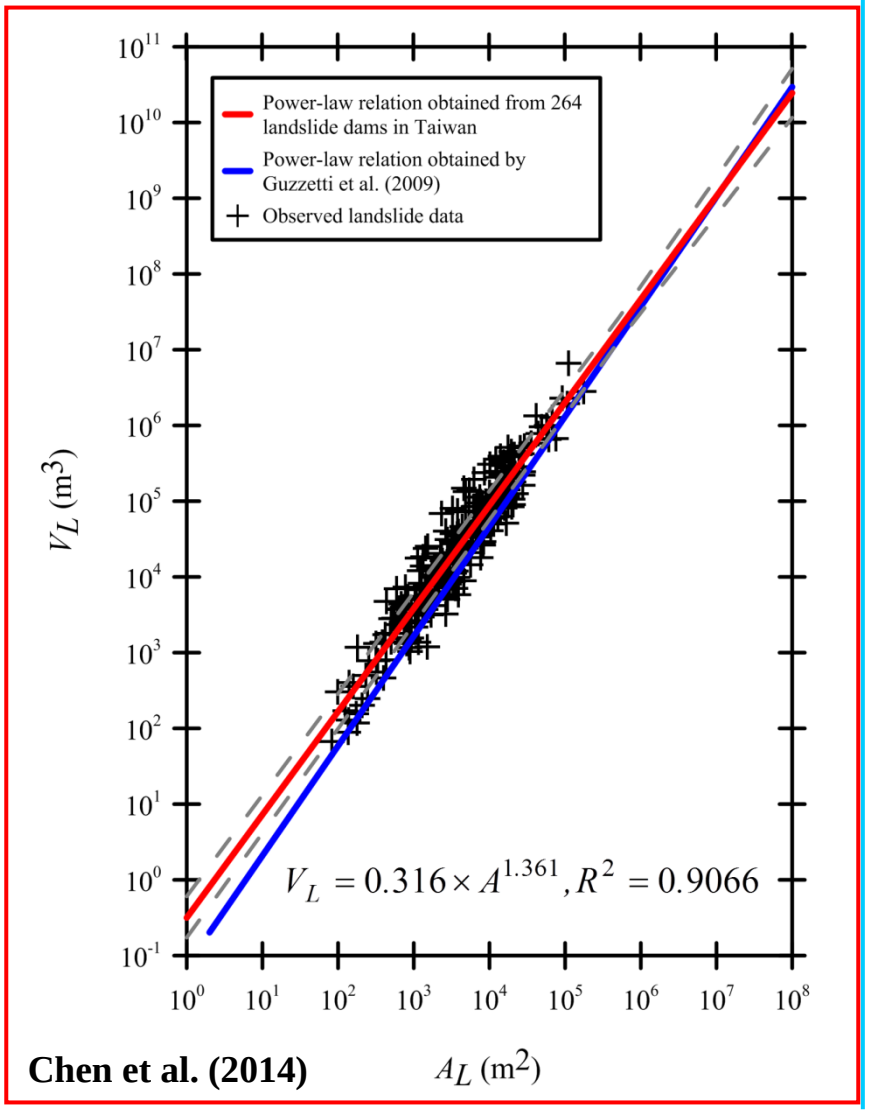
↓

Landslide area A_L (m²)

↓

Landslide volume V_L (m³)

$$V_L = 0.316 A_L^{1.361}, R^2 = 0.9066$$



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↓

Landslide volume V_L (m³)

↓

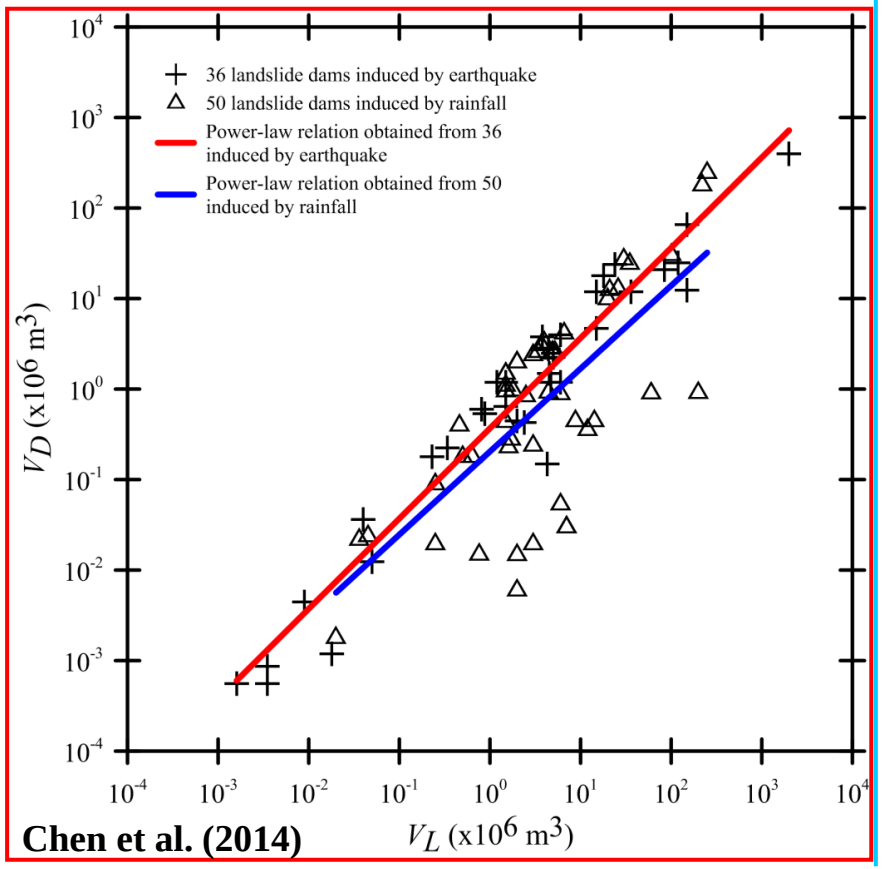
The volume of landslide dam V_D (m³)

Earthquake:

$$V_D = 0.368 V_L^{0.998}, R^2 = 0.9430$$

Rainfall:

$$V_D = 0.204 V_L^{0.917}, R^2 = 0.5124$$



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Landslide area A_L (m^2)

↓

Landslide volume V_L (m^3)

↓

The volume of landslide dam V_D (m^3)

↓

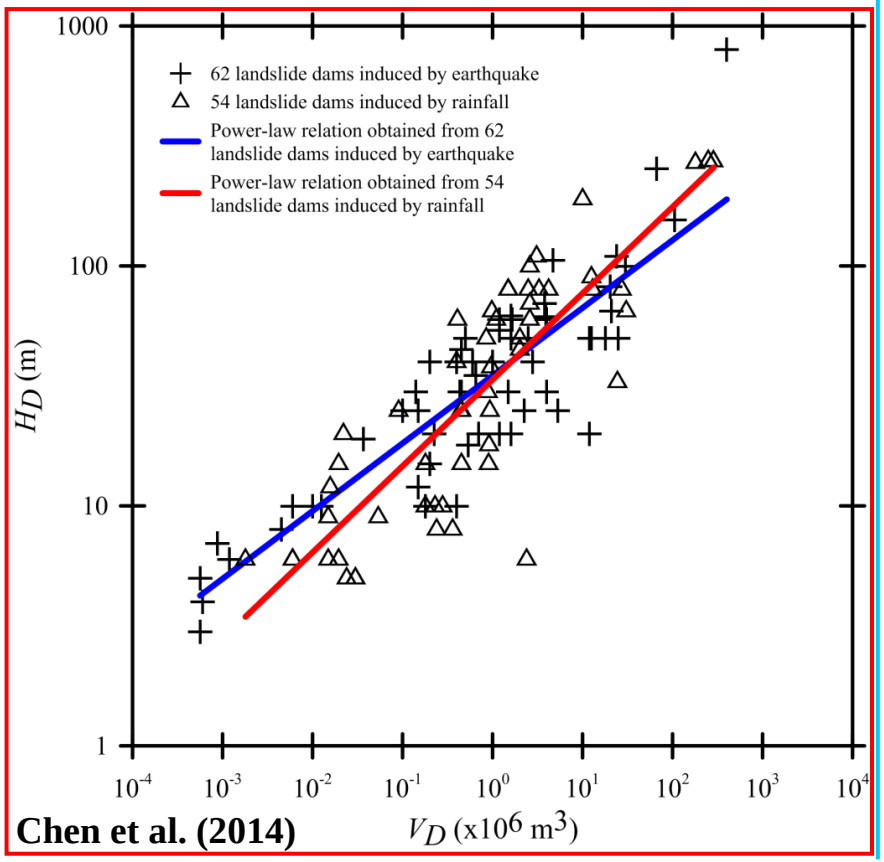
Dam height H_D (m)

Earthquake:

$$H_D = 34.921 V_D^{0.282}, R^2 = 0.7648$$

Rainfall:

$$H_D = 33.570 V_D^{0.360}, R^2 = 0.7207$$



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↓

Landslide area A_L (m²)

↓

Landslide volume V_L (m³)

↓

The volume of landslide dam V_D (m³)

↓

Dam height H_D (m)

↓

River bed slope θ (°)

↓

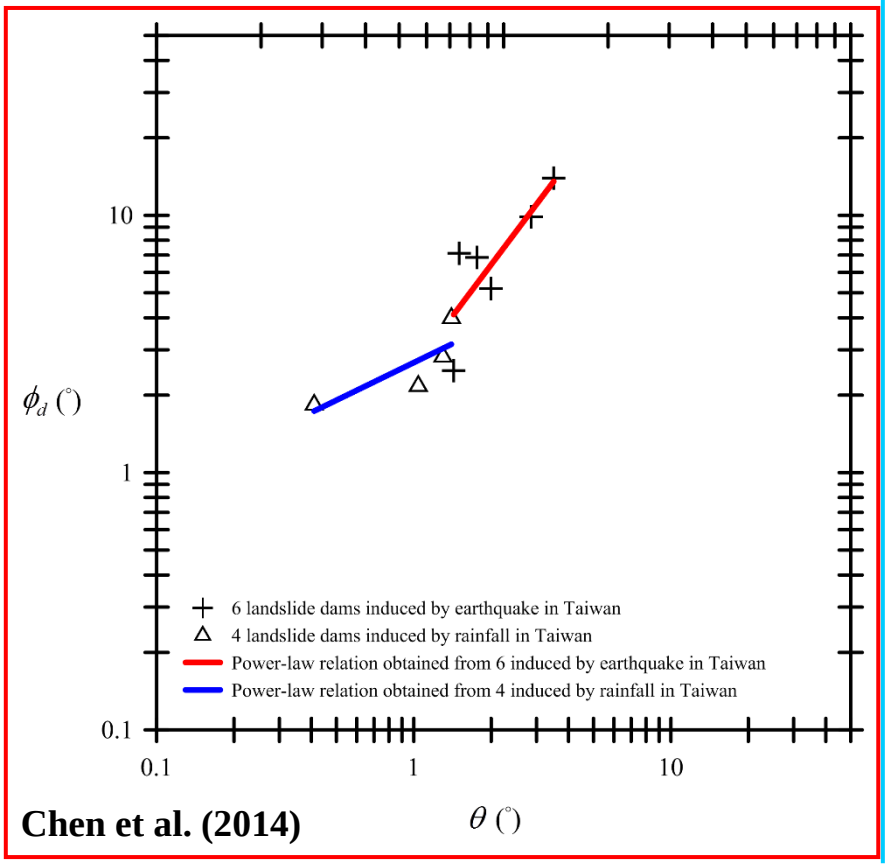
The dam in downstream direction ϕ_d (°)

Earthquake:

$$\phi_d = 2.559\theta^{1.330}, R^2 = 0.6601$$

Rainfall:

$$\phi_d = 2.677\theta^{0.486}, R^2 = 0.6632$$



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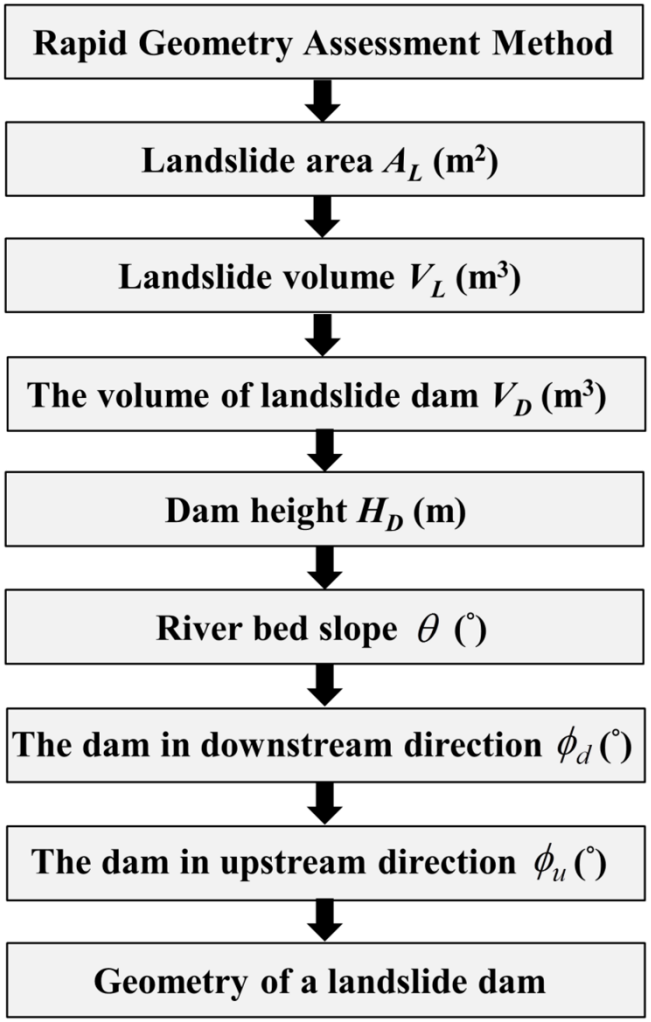
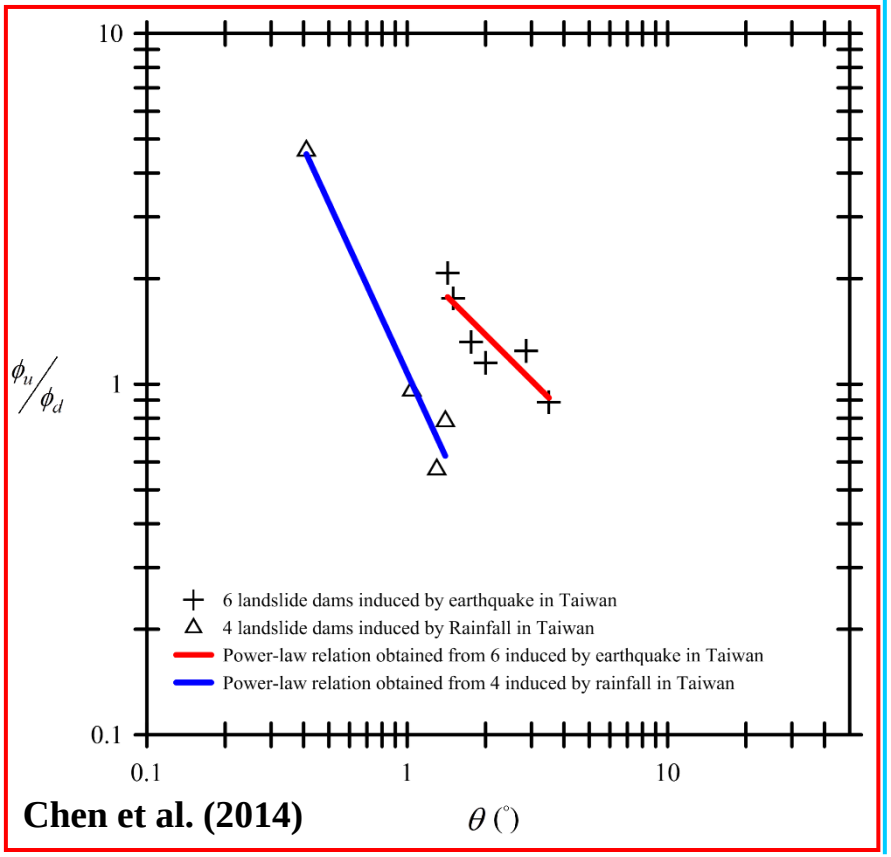


Earthquake:

$$\phi_u = 2.308\phi_d\theta^{(-0.739)}, R^2 = 0.7719$$

Rainfall:

$$\phi_u = 1.075\phi_d\theta^{(-1.613)}, R^2 = 0.9625$$



Chen et al. (2014)

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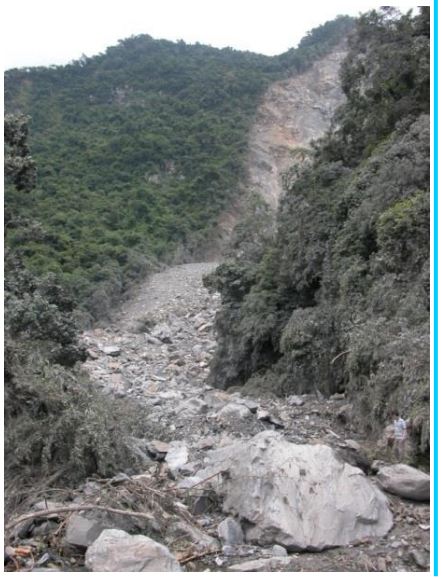
The establishment process of geometry assessment model

- Time : July 16, 2006
- Location : Lung-Chuian river, Taitung
- Trigger : Earthquake
- Area of landslide : 160 x 10^3 m^2
- Volume of landslide : 600 x 10^3 m^3
- Height of landslide dam : 35 m
- Volume of landslide lake : 800 x 10^3 m^3
- Type of dam failure : Overtopping

Photos provided by DPRC, NCKU

Chen et al. (2014)



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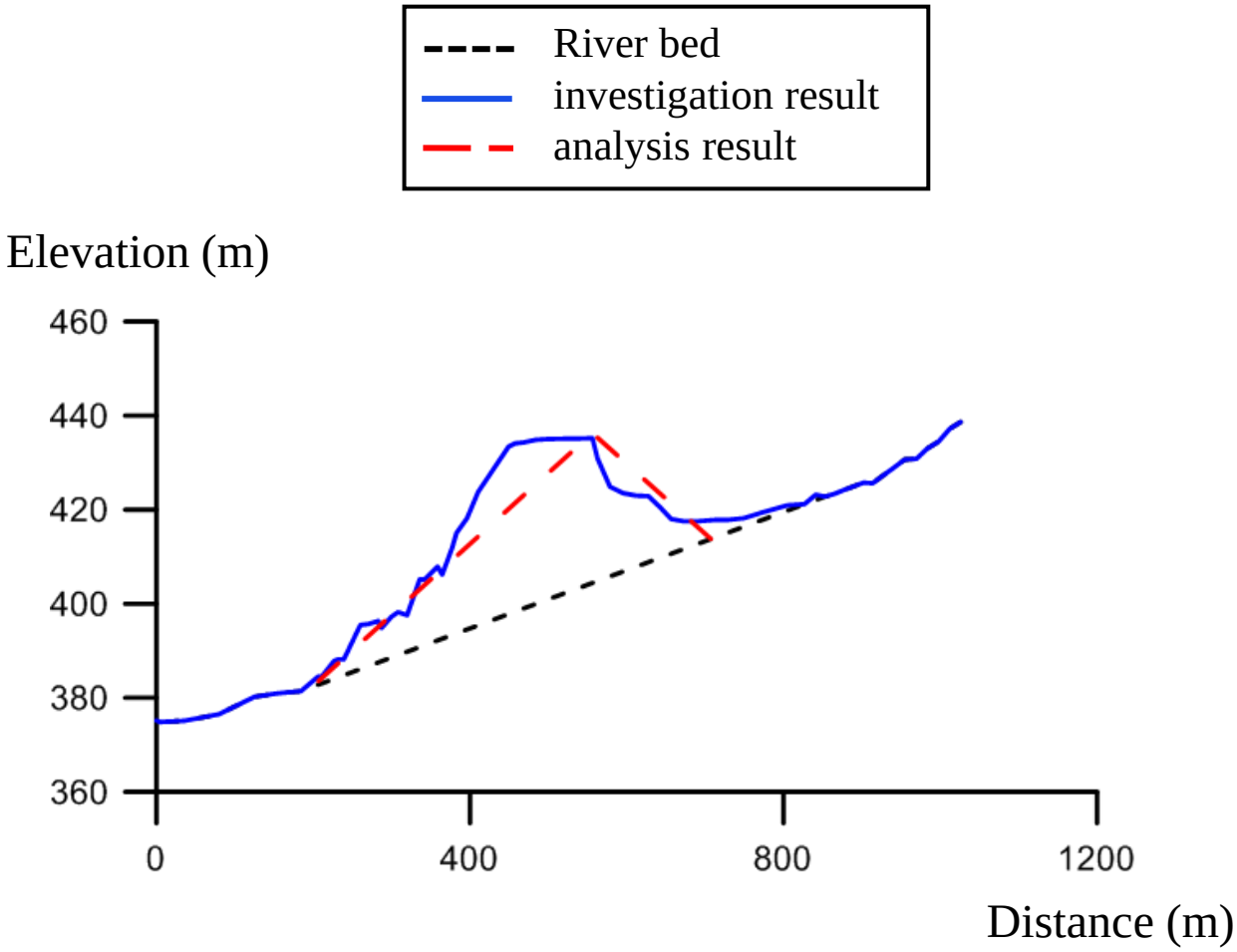

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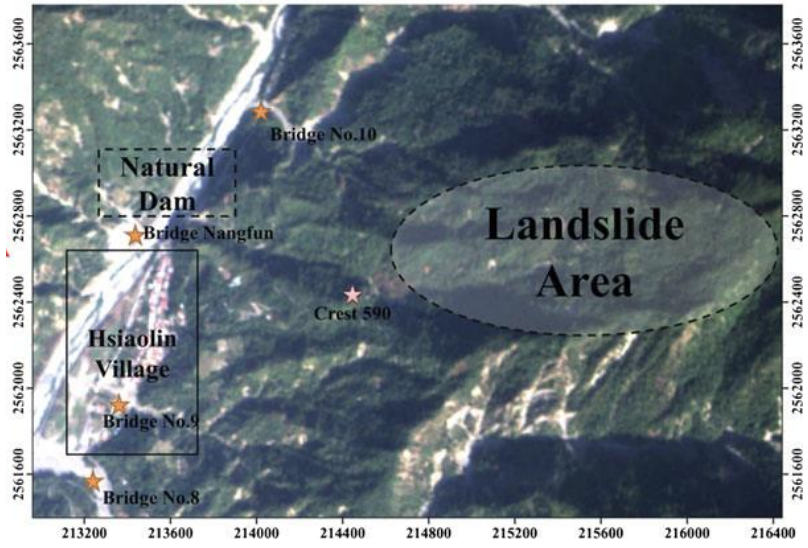
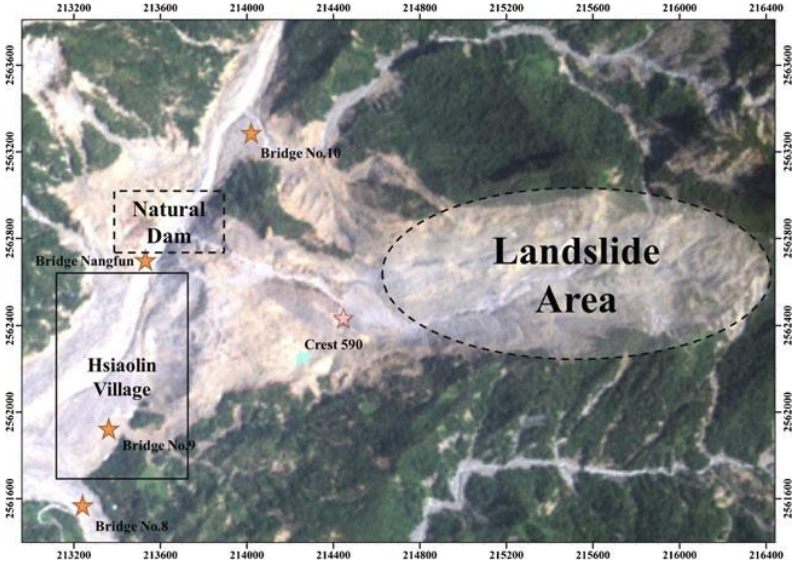
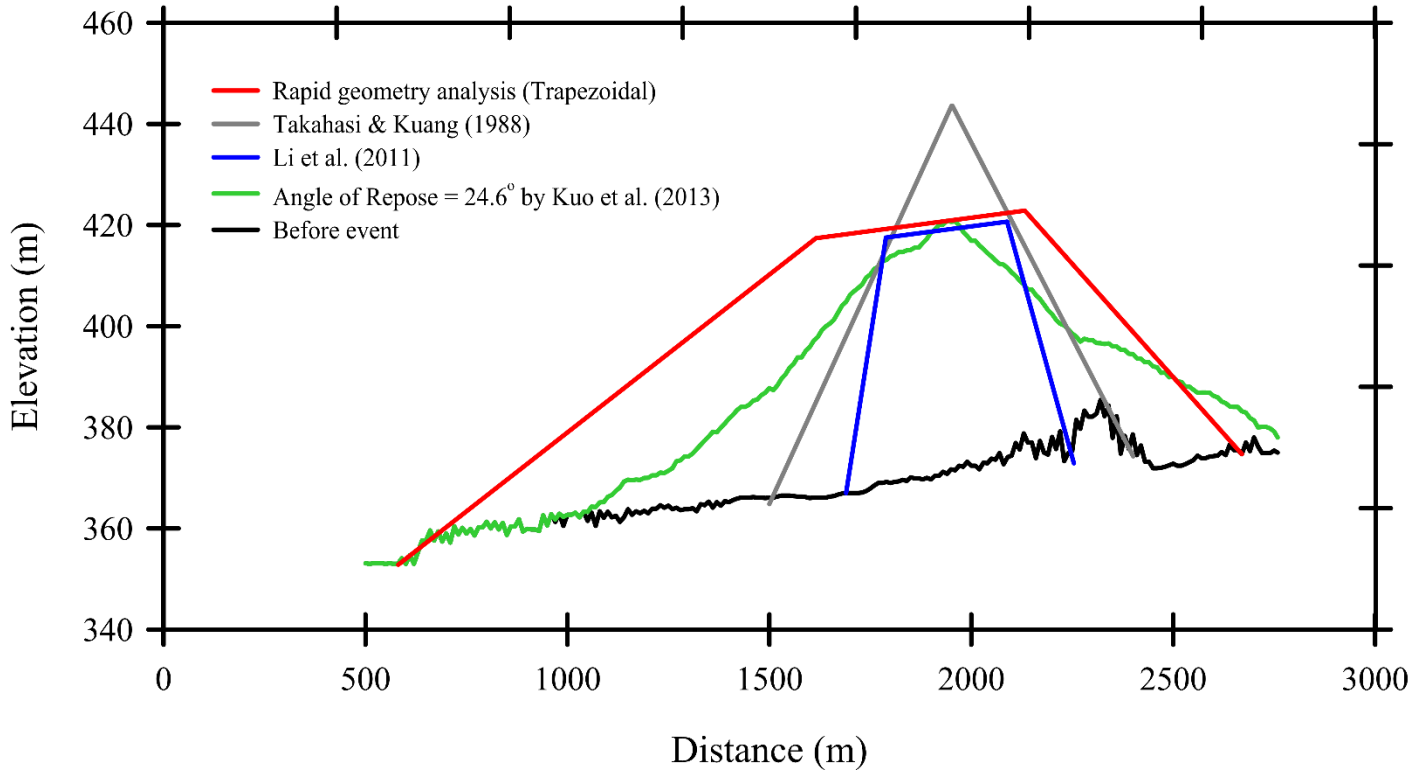
- Time : August 8, 2009
- Location : Hsiaolin Village , Kaohsiung
- Trigger : Rainfall
- Area of landslide : 609 x 10^3 m^2
- Volume of landslide : 23580 x 10^3 m^3
- Height of landslide dam : 50 m
- Type of dam failure : undefined

Kuo et al. (2013)





The establishment process of geometry assessment model



Chen et al. (2014)

- Introduction
- Formation mechanism
- **Geometry of a landslide dam**
- Conclusions

Conclusions

- **The obtained the potential location and dam geometry of landslide dam, provides important information for further dam stability analysis and emergency response plans.**

- **In the future, we still necessary to update our knowledge of related topics such as landslide-dammed lake failure, disaster assessment, prevention, early warning and evolution trend etc.**

- **Disaster prevention ~ Hope for the best, but prepare for the worst. And learn from experience.**

Thank You