Landslide Dam Failure

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Outline

- Introduction
- Failure mechanism
- Stability assessment
- Conclusions

Introduction

The hazards of landslide dam

Affected by rainfall or earthquake on both sides of the valley, it will be occurred the collapse, landslide, debris flow, etc. The soil mass of the landslide could not be immediately carried downstream by the river flow, and accumulated in the river to form a dam.

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

The backwater upstream of the dam will be destroyed the buildings, roads and farmland etc.

It is not easy to predict the dam break time of barrier lake which makes the disaster suddenly, large impact and wide impact which seriously threatens the safety of life and property of downstream residents.

The hazards of landslide dam

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.

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.

As a result of a breach of a landslide dam an anomalous flood wave may propagate downstream. The higher the peak discharge originated by the dam failure, the more devastating the effects.

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

The hazards of landslide dam

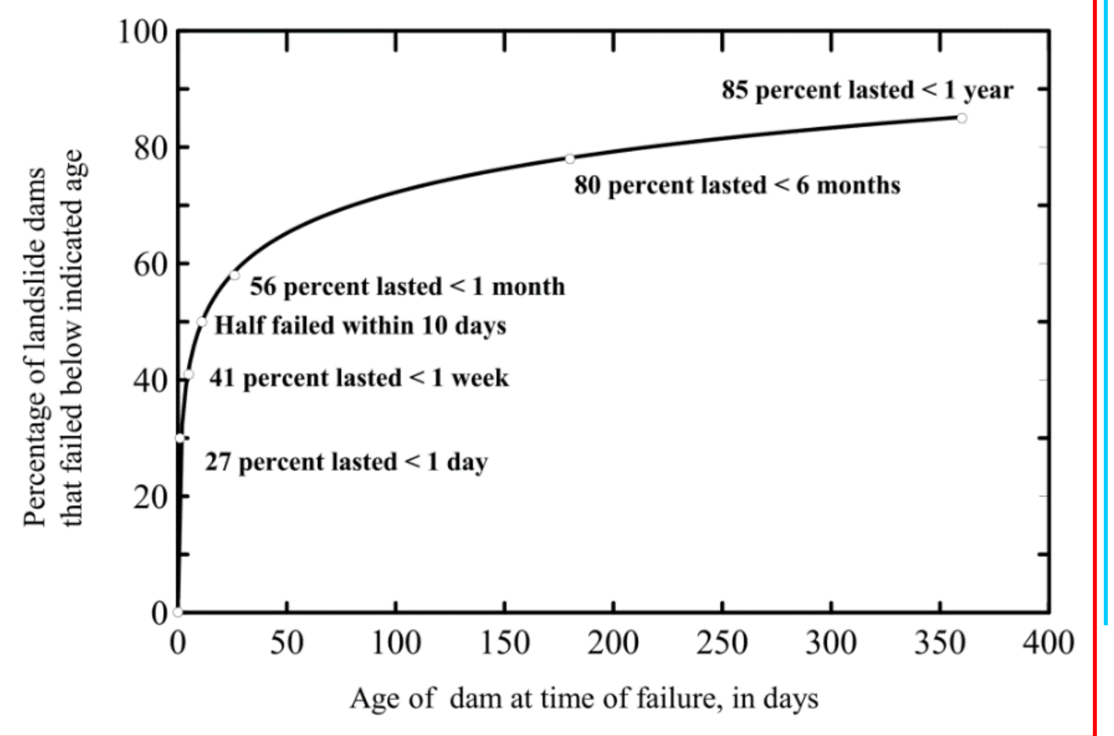
https://www.youtube.com/watch?v=8vUttWBm5J4

The hazards of landslide dam

Video provided by DPRC, NCKU

The hazards of landslide dam

Costa and Schuster (1988) studied 73 landslide dams throughout the world. The result shows that 27% of these dams failed within a day and 41% of these dams lasted less than a week. Only 15% of the dams last a year or longer. Peng and Zhang (2012) studied of the 204 recorded landslide dam cases with failure information, 87% failed within 1 year, 71% within 1 month, 51% within 1 week, and 34% within 1 day.



Costa & Schuster (1988)

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The hazards of landslide dam

Costa and Schuster (1988) suggested that factors affecting the duration of natural dams can be assessed by dam volume, geometry, material properties, composition size, infiltration rate, and post-dam impoundment supply rate, etc.

Three of these factors are most important in relation to the existence time of natural dams:

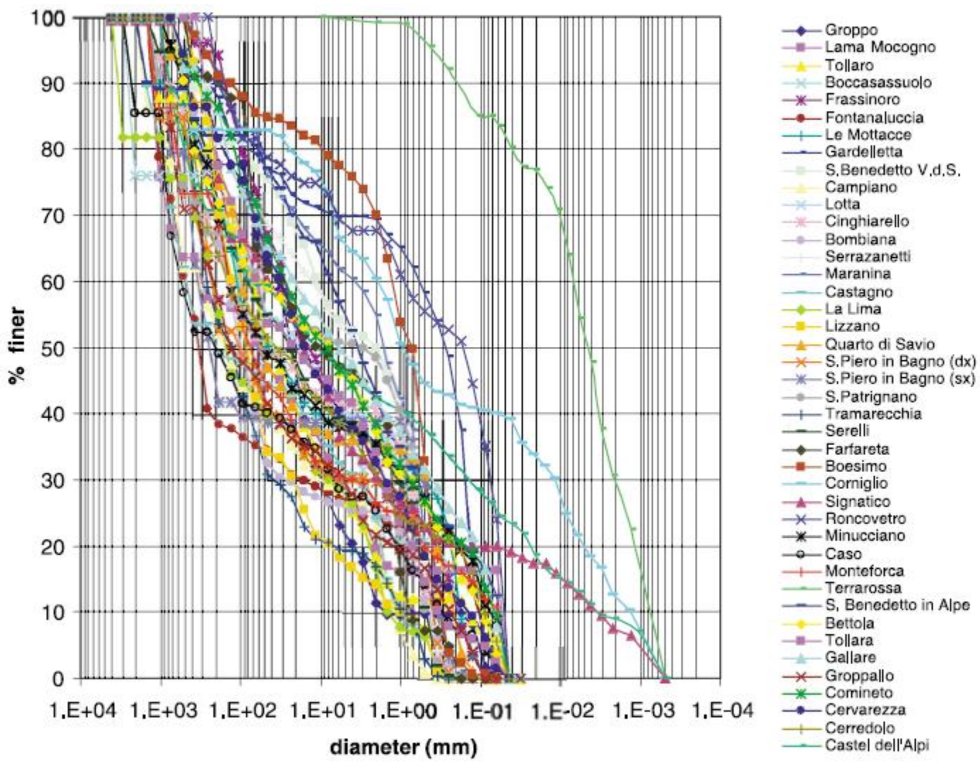
1. the rate of inflow supply to the impoundment area behind the dam.

2. the shape and size of the natural dam.

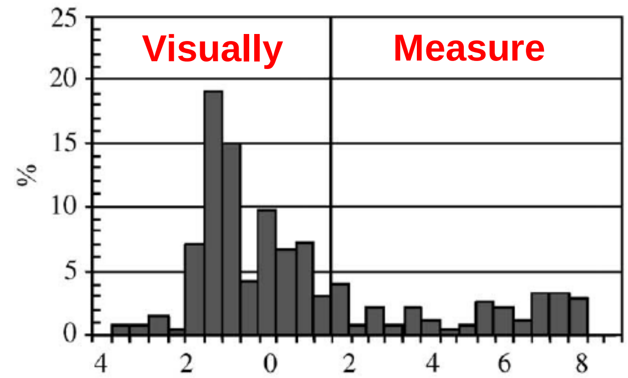
3. The characteristics of the soil and sand materials that make up the natural dam.

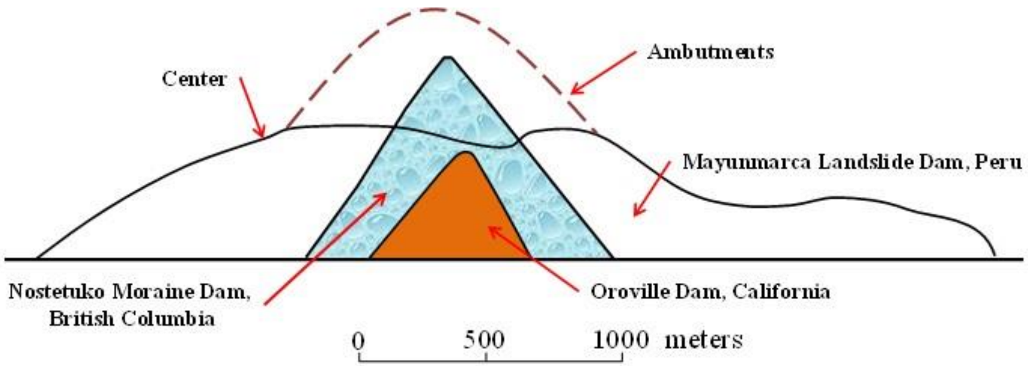
Failure mechanism

Material properties of landslide dam



Casagli et al. (2003)





Material properties of landslide dam

Earthquake-induced landslides form dams

Dam structure is loose, low water content, high porosity, low cohesion and uneven distribution of grain size.

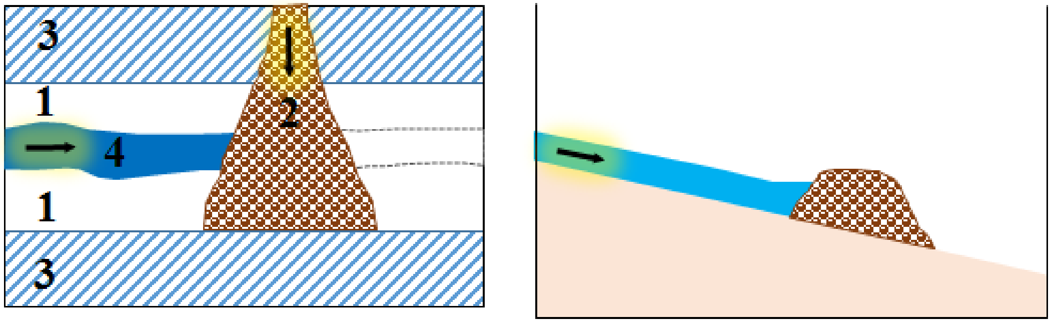
Rainfall-induced landslides form dams

High water content, low porosity, low internal friction angle, high cohesiveness and uneven particle size distribution.

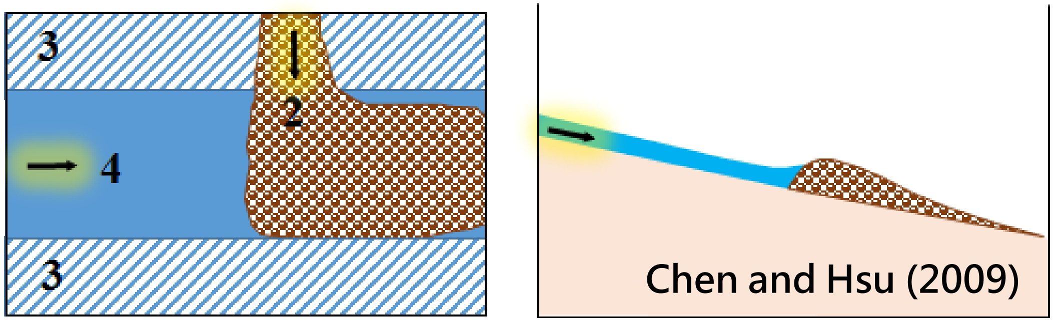
Rainfall-induced debris flow form dams

High water content, low porosity, low permeability, high cohesiveness and uneven particle size distribution.

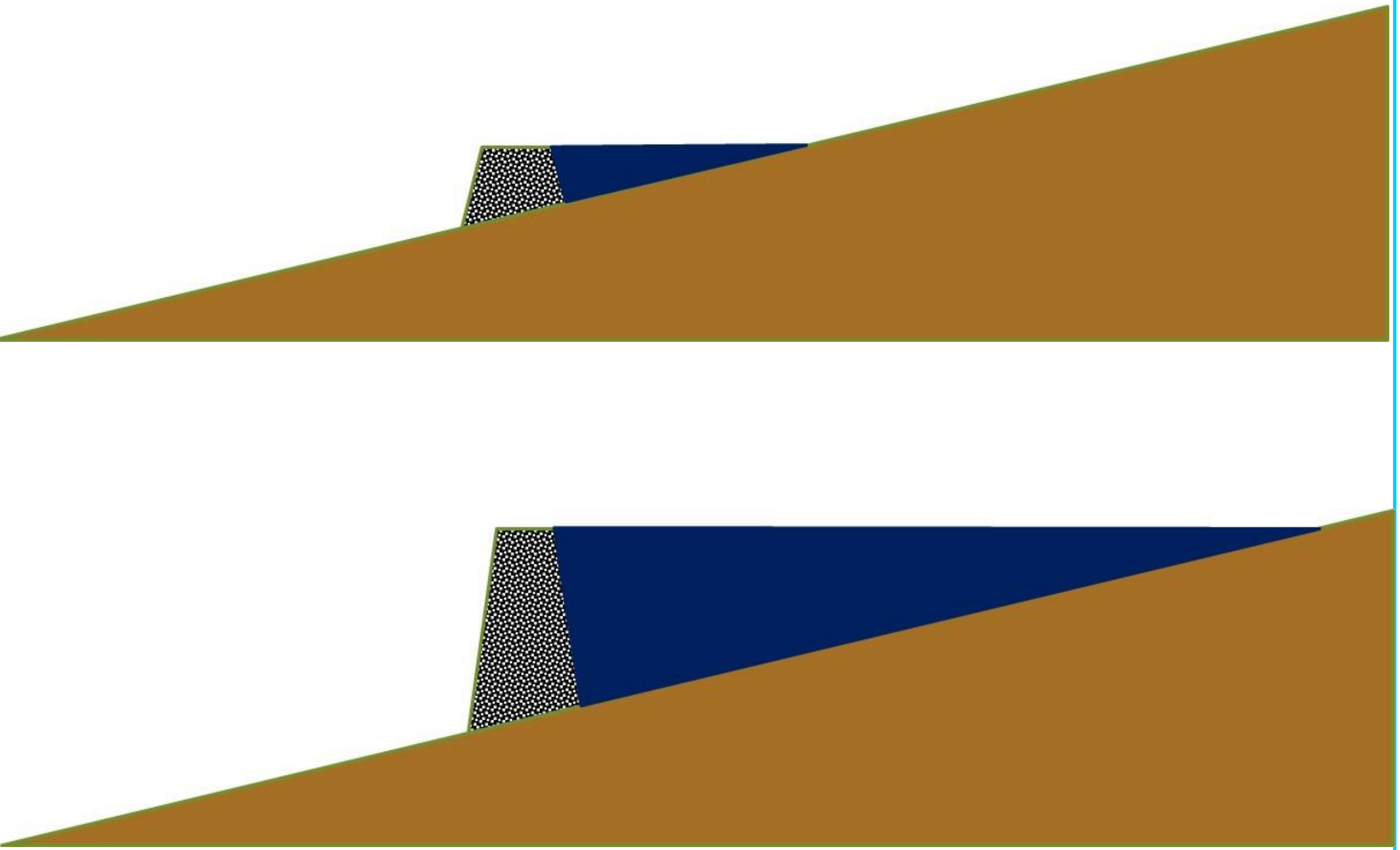
Earthquake-induced landslides form dams



Rainfall-induced debris flow form dams



Height characteristics of landslide dam



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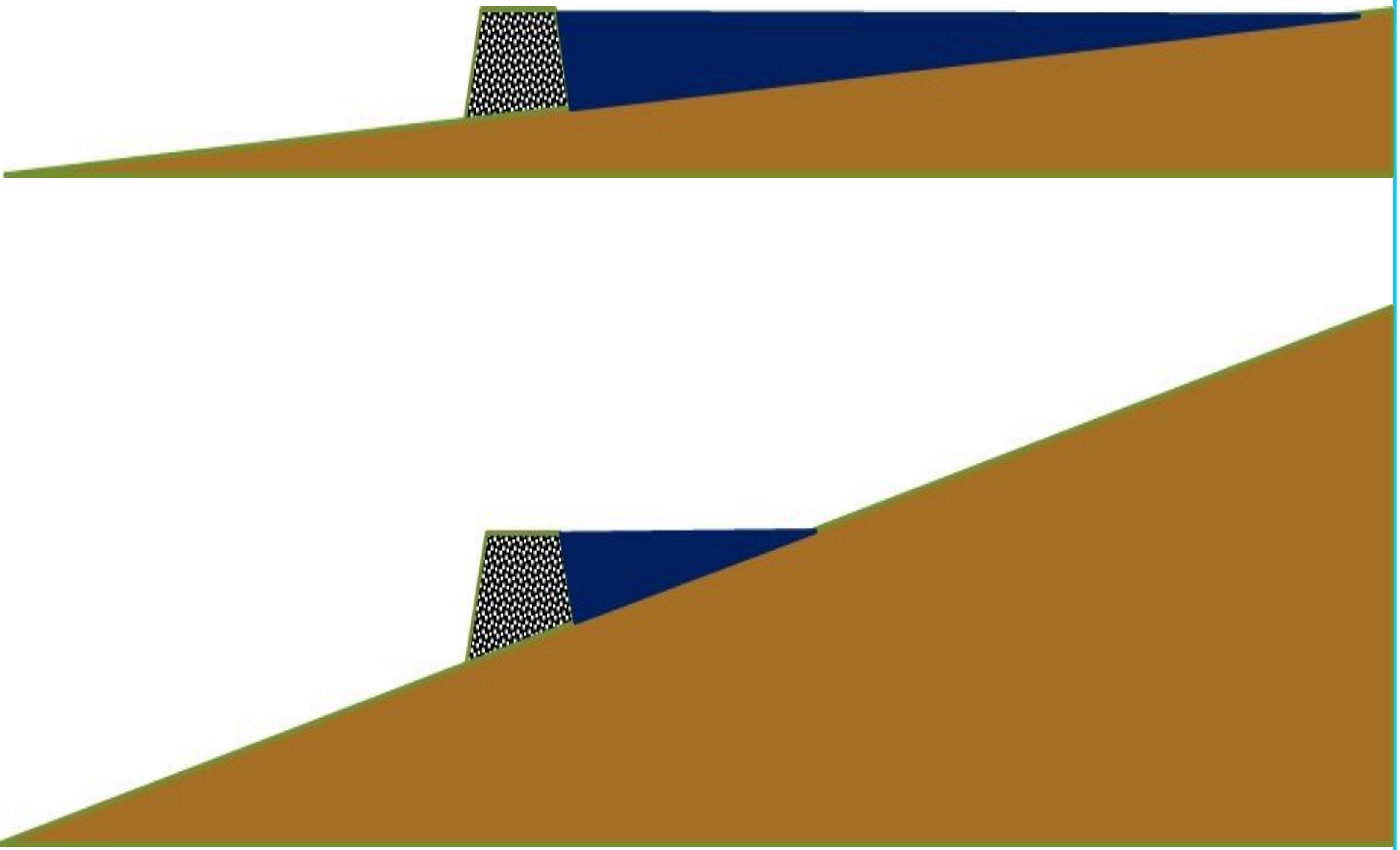
River slope characteristics of landslide dam



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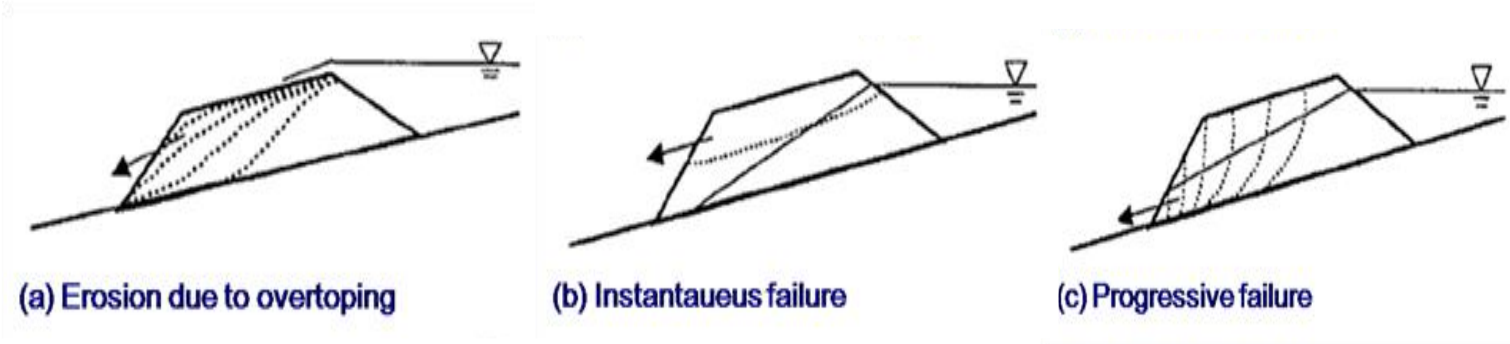
Failure types of landslide dam

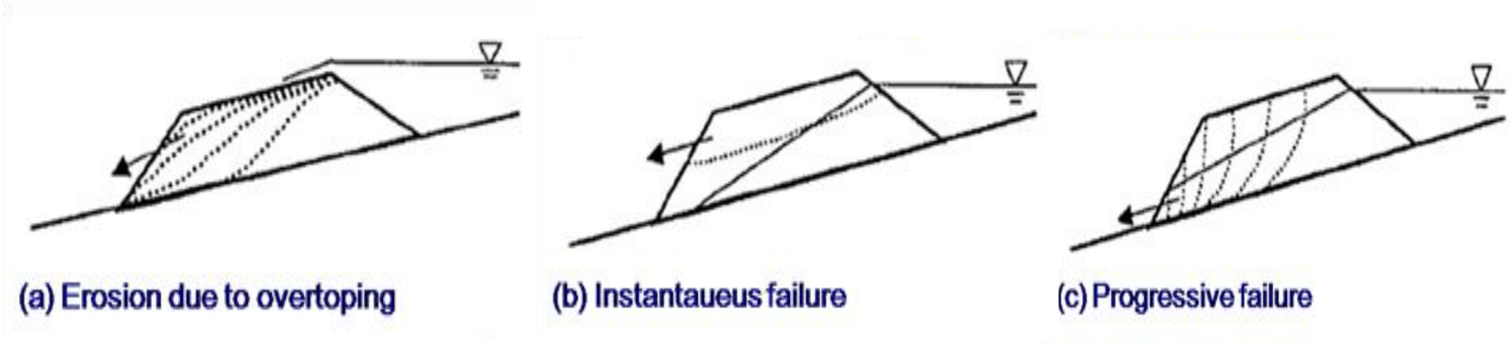


Takahashi & Kuang (1988)

Erosion due to overtopping: **The overflow flood will continue to scour the top of the dam and the downstream face of the dam to entrain the body material downstream, causing the dam body to become thinner and eventually collapse.**

Instantaneous failure: **The infiltration in the dam causes the dam body to increase its own load, so that the frictional resistance between the soil particles decreases and reaches the critical shear stress and then suddenly slips and breaks.**

Failure types of landslide dam



Takahashi & Kuang (1988)

Progressive failure: **The toe of the dam is hollowed out due to the phenomenon of pipe welling and the foot of the downstream slope of the dam body, and the damage has been gradually developed along the slope in the direction of the top of the dam to the top of the dam eventually leading to the damage of the dam body.**

Failure types of landslide dam

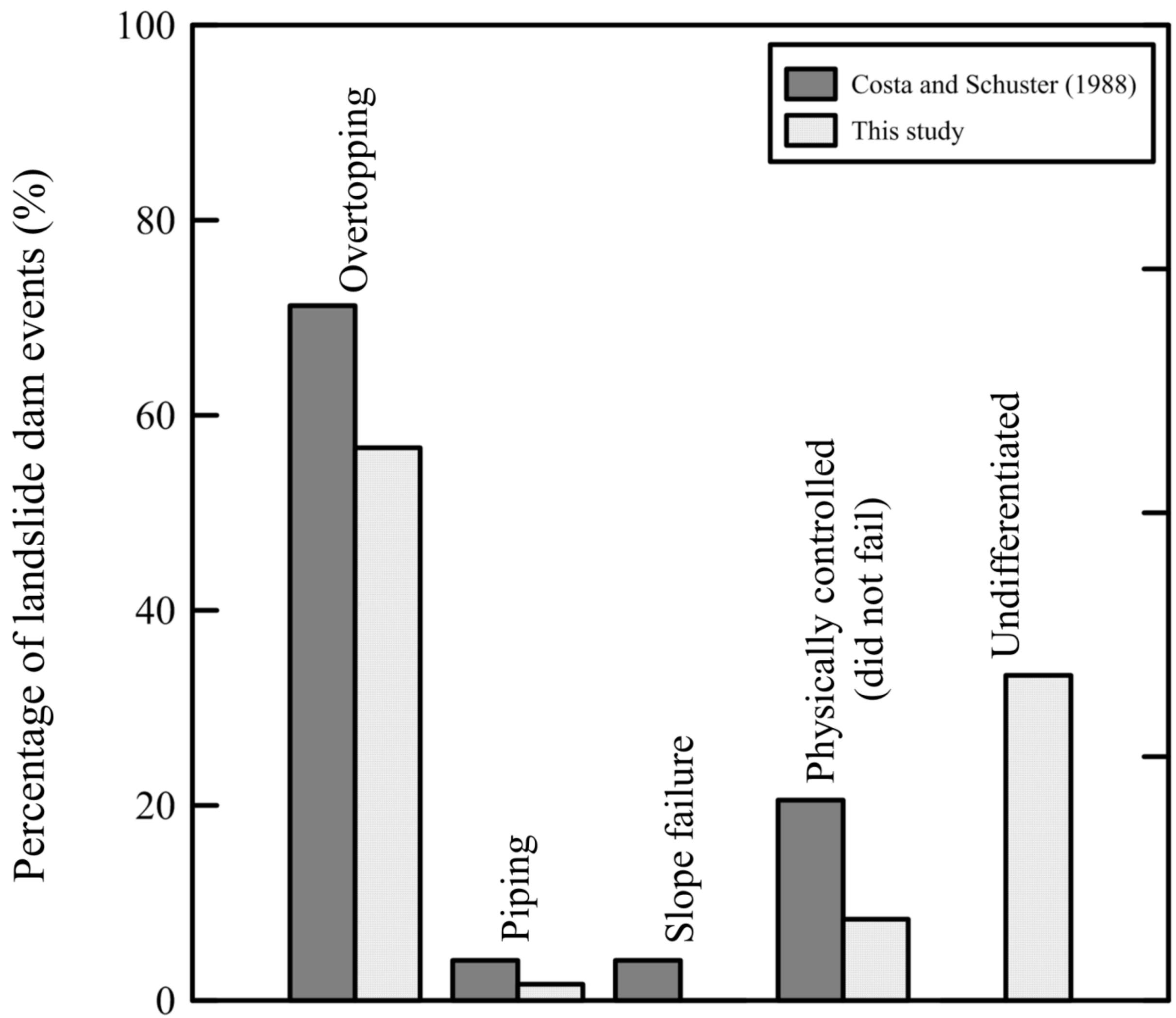
Overtopping: It is a primary mechanism of landslide dam failure which occurs after the overfilling of the dammed reservoir.

Piping: It is a kind of internal erosion caused by the migration of particles to free exits or by the uncontrolled saturation and seepage forces.

slope failure: It can easily occur when a landslide dam has steep upstream and downstream faces, as well as high pore-water.

Zhu et al. (2019)

Failure types of landslide dam



Costa & Schuster (1988)

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Failure types of landslide dam

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Stability assessment

Stability assessment of landslide dam

To reduce the hazards caused by landslide dams, two important risk assessments must be conducted immediately upon the formation of a landslide dam, i.e., an assessment of dam stability and an assessment of dam-break discharge.

Hence, several researchers have proposed methods to conduct a preliminary risk assessment of dam stability based on morphological and watershed characteristics.

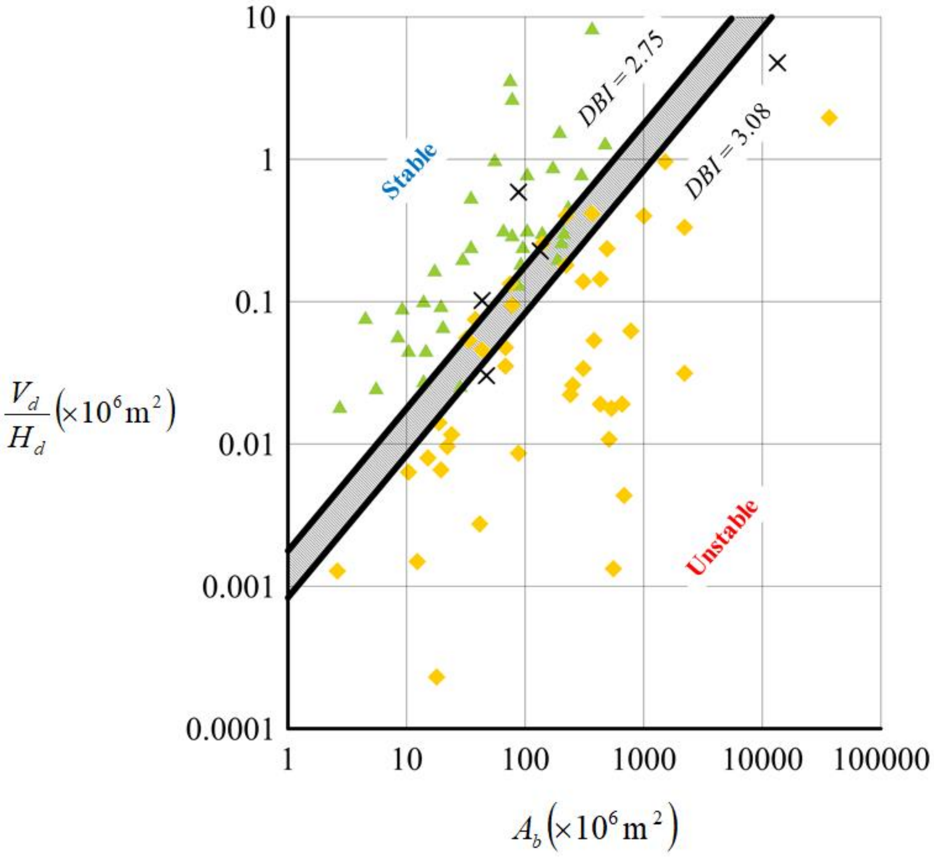
Also, some have used the geometrical and hydrological parameters of a dam to establish an empirical formula for evaluating landslide dam-break discharge.

The dimensionless blockage index

- *DBI* (Ermini & Casagli,2003)

$$DBI = \log\left(\frac{A_b \times H_d}{V_d}\right)$$

$$DBI \begin{cases} < 2.75 & \text{stable} \\ > 3.08 & \text{unstable} \end{cases}$$



A_b : watershed area (m^2)

H_d : dam height (m)

V_d : dam volume (m^3)

Discriminant and logistic regression model

- **The method of Dong et al. (2009)**
  Discriminant analysis

$$AHWL\_Dis = -2.62\,log(A_b) - 4.67\,log(H_d) + 4.57\,log(L) + 2.67\,log(W) + 8.26$$

$$AHV\_Dis = -2.13\,log(A_b) - 4.08\,log(H_d) + 2.94\,log(V_d) + 4.09$$

AHWL_Dis & AHV_Dis <0 unstable

- **The method of Dong et al. (2011)**
  Logistic regression model

$$AHWL\_Log = -2.22\,log(A_b) - 3.76\,log(H_d) + 3.17\,log(L) + 2.85\,log(W) + 5.93$$

$$AHV\_Log = -4.48\,log(A_b) - 9.31\,log(H_d) + 6.61\,log(V_d) + 6.39$$

AHWL_Log & AHV_Log <0 unstable

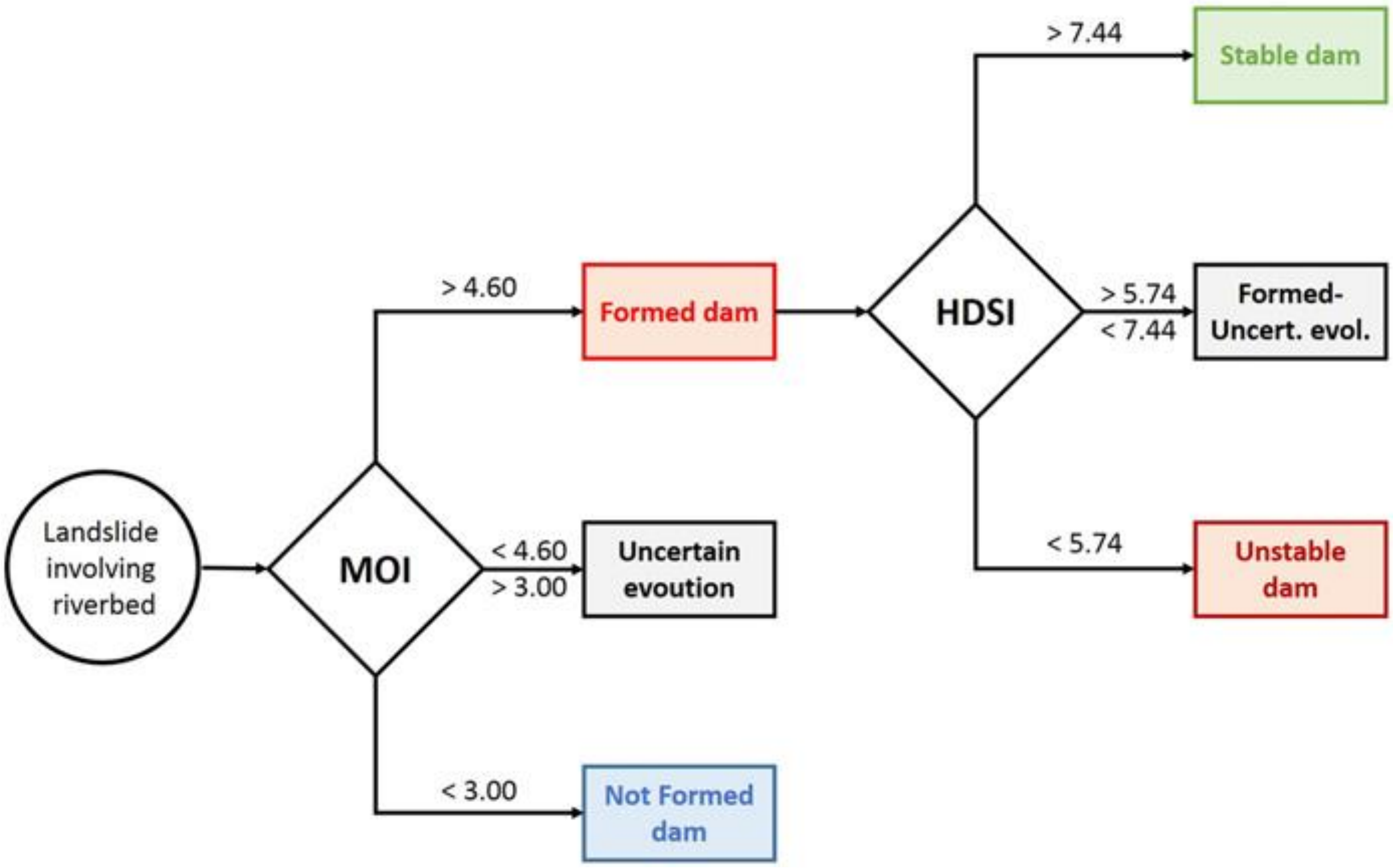
A_b : watershed area (m^2)

H_d : dam height (m) **L : dam length (m)**

V_d : dam volume (m^3) **W : dam width (m)**

Hydromorphological dam stability index

- *HDSI* (Stefanelli et al. (2016)



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Hydromorphological dam stability index

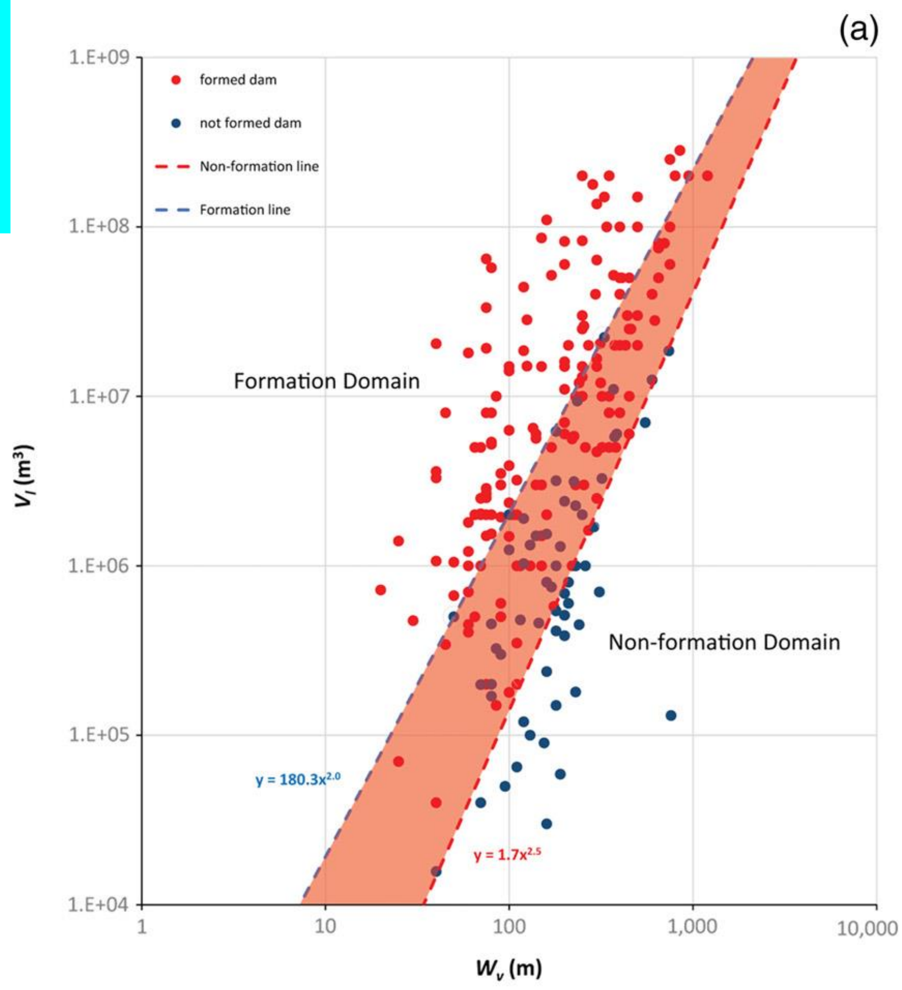
- *HDSI* (Stefanelli et al. (2016))

$$MOI = \log\left(\frac{V_L}{W_V}\right)$$

$$MOI \begin{cases} < 3.00 & \text{not formed} \\ > 4.60 & \text{formed} \end{cases}$$

V_L : landslide volume (m^3)

W_V : river width (m)



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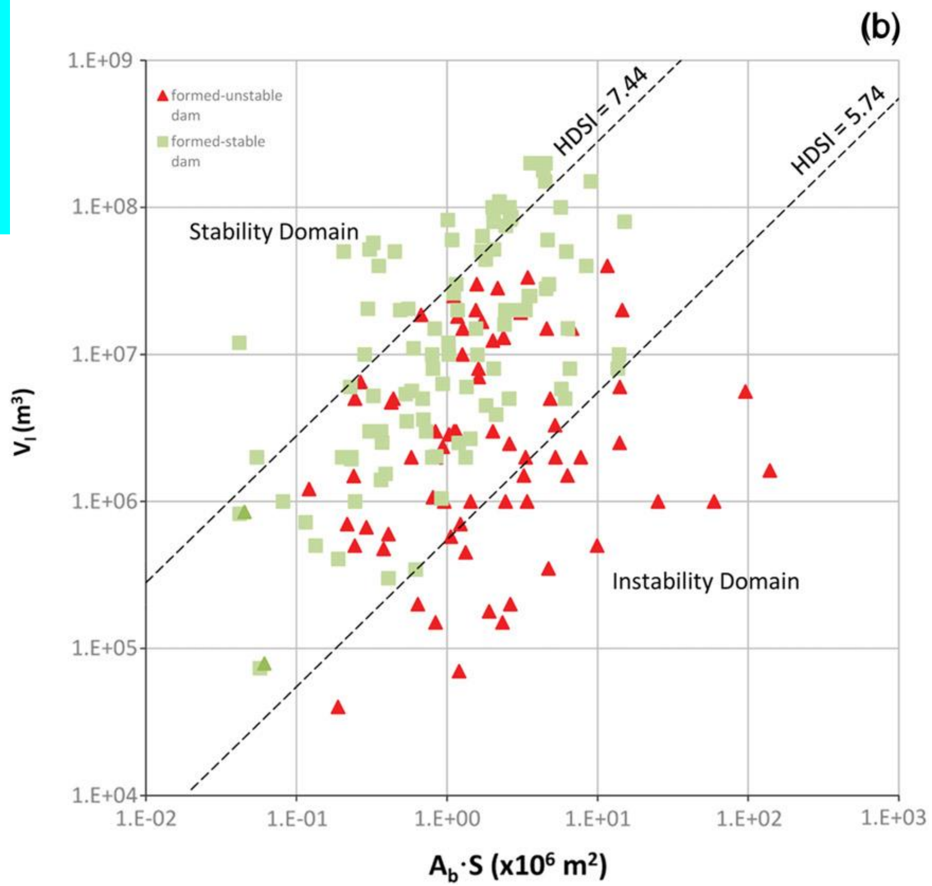
Hydromorphological dam stability index

- *HDSI* (Stefanelli et al. (2016)

$$HDSI = \log\left(\frac{V_L}{A_b S}\right)$$

$$HDSI \begin{cases} < 5.74 & \text{stable} \\ > 7.44 & \text{unstable} \end{cases}$$



V_L : landslide volume (m^3)

A_b : watershed area (m^2)

S : river slope (°)

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Conclusions

- **Landslide dams remain a physical process which is not well understood, because they are the result of the complex interaction between river and slope dynamics. The prevailing factor out of these two is often fundamental in controlling the fate of the landslide dam.**

- **Usually, landslides triggered by earthquakes are capable of carrying a greater amount of material to the river channel, thus forming a more substantial landslide dam.**

- **Three failure mechanisms typically caused the instability and failure of landslide dams, including overtopping failure, piping failure, and slope failure.**

- **The clarification of the potential damage pattern of landslide dams will facilitate the formulation of disaster prevention and response strategies, and help improve disaster prevention and response capabilities.**

Soil and Water Conservation

Thank You