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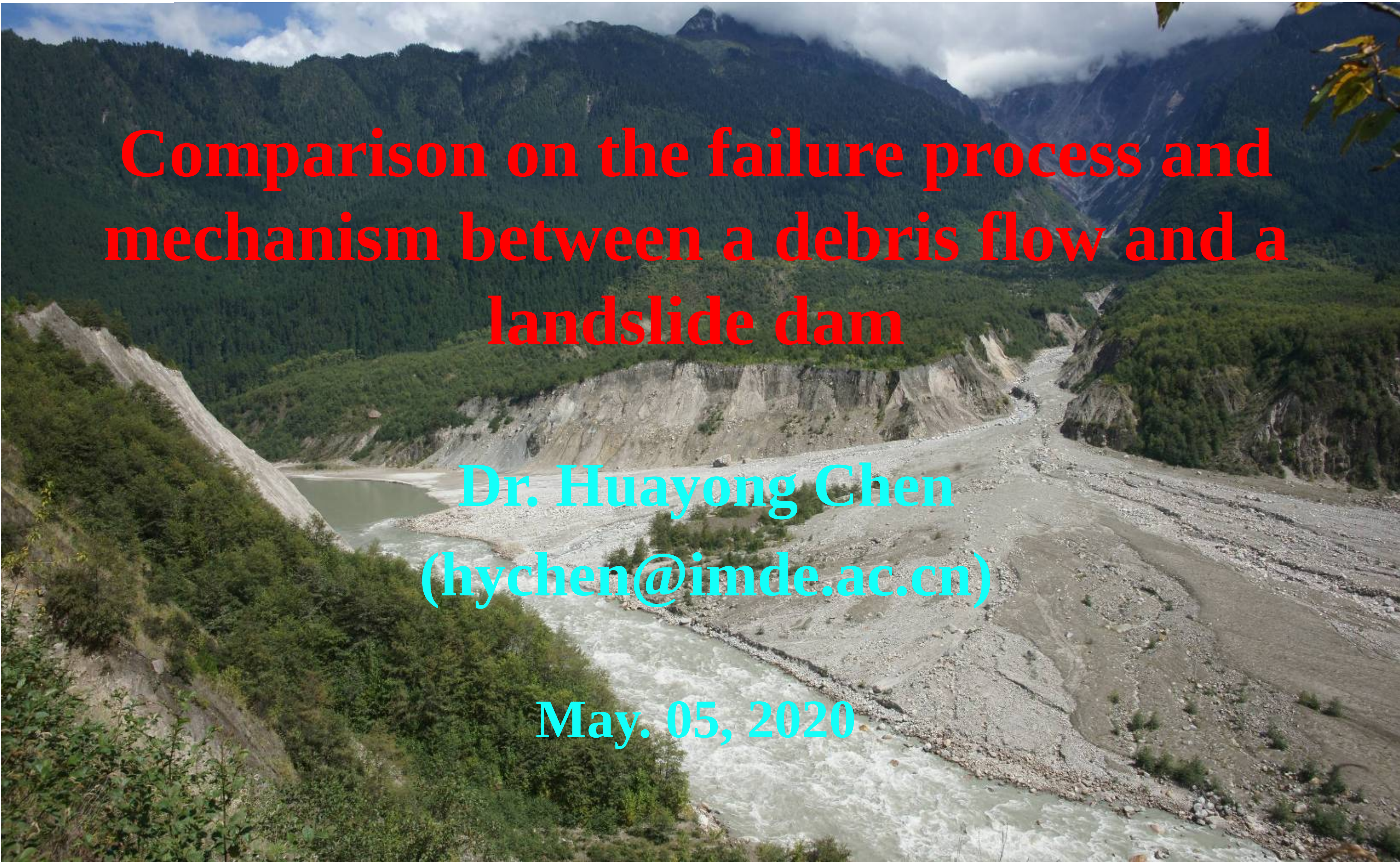

Comparison on the failure process and mechanism between a debris flow and a landslide dam

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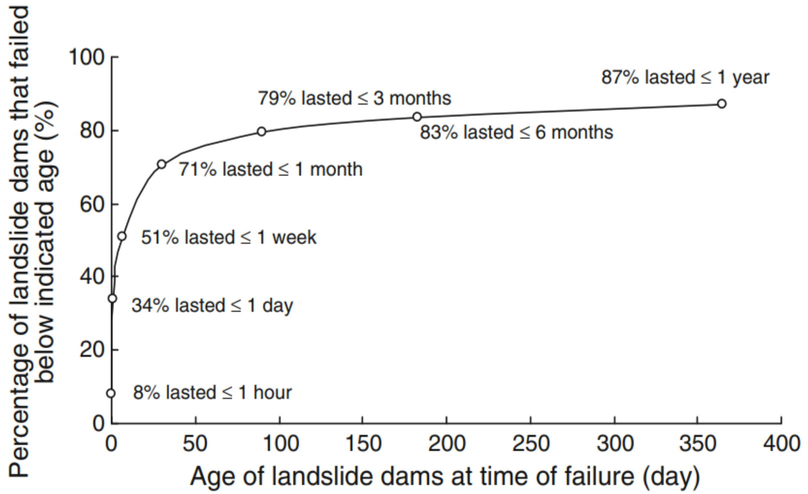
I、 Research background

Tangjiashan landslide dam in 2008

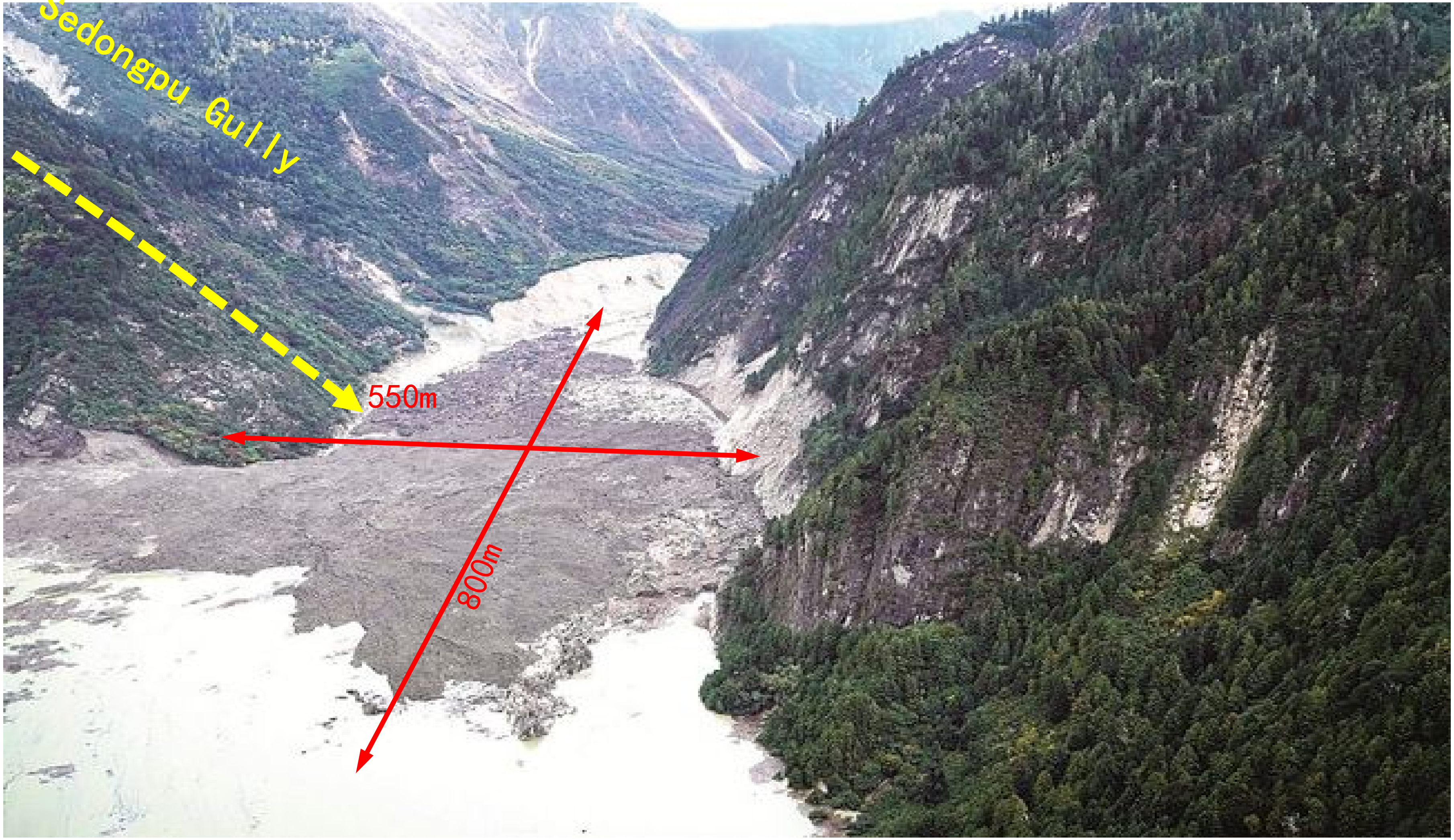
Guxiang gully debris flow dam in 1953

Midui moraine dam in 1988



The dam is 611.8 meters wide, 803.4 meters along the flow direction, 124.4 meters high, with a volume of about 20.40 million cubic meters. The peak discharge was about 6500 m^3/s.

The Zhouqu debris flow event occurred in Aug.8, 2010,in Gansu province. It was also triggered by an intensive rainfall (**77mm in 1 hr.**) and led to **1765 people dead or missing**, more than **5000 housed buried or destroyed**.



In the morning of October 17, 2018, a large-scale glacier debris flow occurred in Sedongpu, Gala village, Pai Town, Milin County, Linzhi City, Tibet

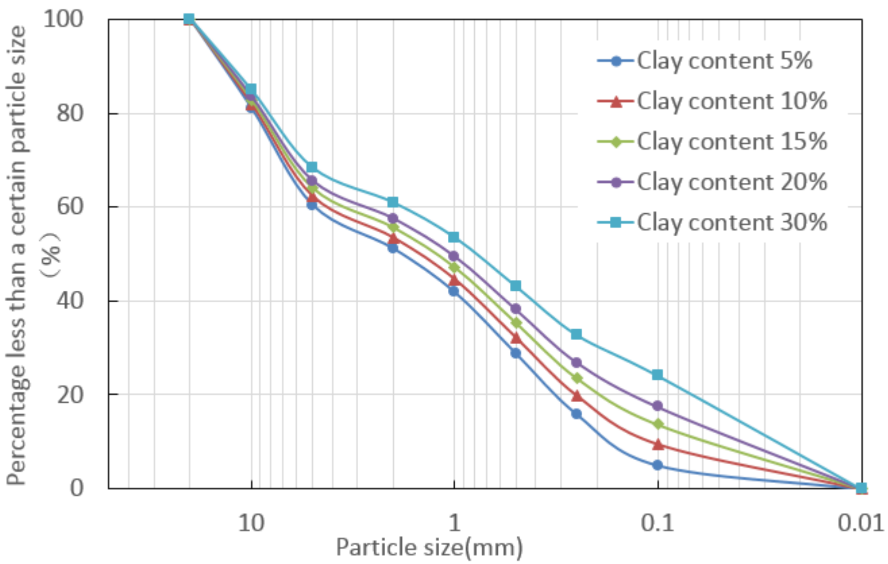
Debris flow blocks the Yarlung Zangbo River and forms a barrier lake

Research status and key scientific issues

Research status	Key scientific issues to be solved
◆ **Landslide dams：** Failure mode of landslide dam, stability analysis of bank slope, cutting erosion rate, peak discharge calculation, evolution calculation, risk assessment and risk management, etc ◆ **Debris flow dams：** Failure mode of debris flow dam and calculation of flood peak discharge, etc	◆ **Landslide dams：** Failure process and mechanism of landslide dam, calculation of peak flow of rupture flood, calculation of dam body material erosion rate, etc. ◆ **Debris flow dams：** The process and mechanism of debris flow dam breaking, calculation of peak discharge of breaking flood, calculation of material erosion rate of dam body, critical conditions of debris flow formed by breaking flood, etc.)

II、Design of the experimental model

Concrete gradation of experimental materials



Experimental setup

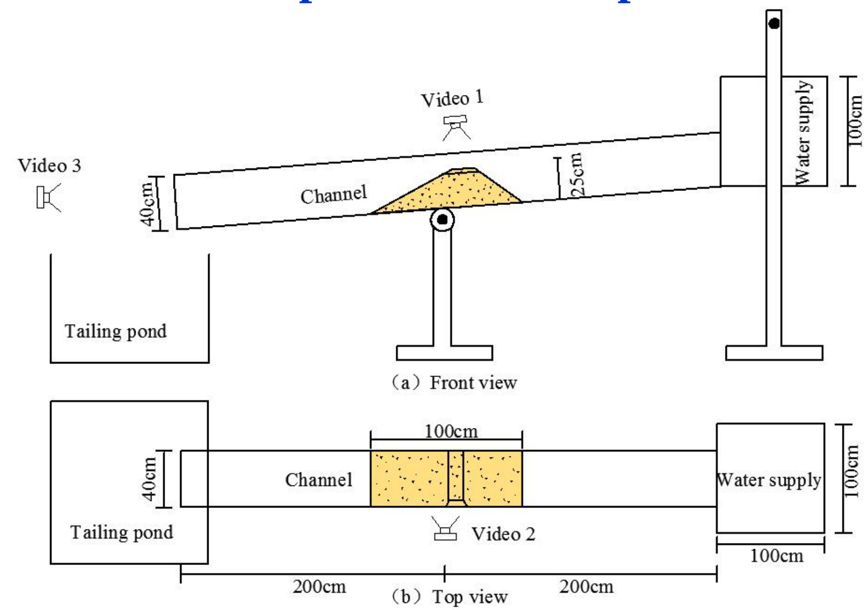
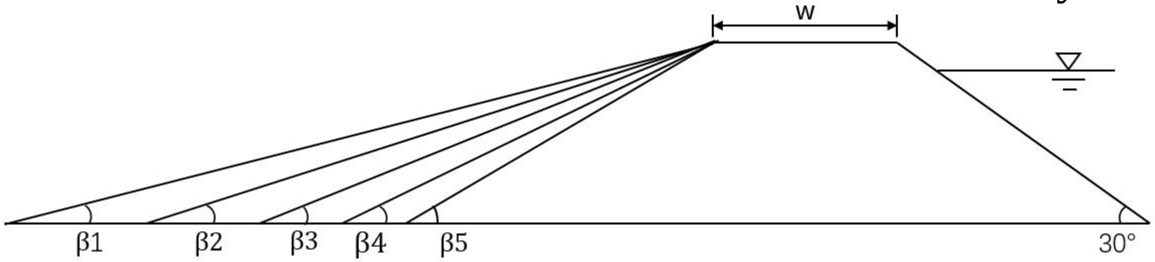


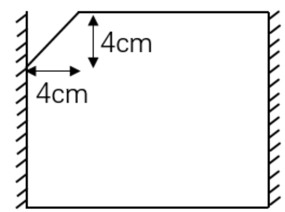
Table of test parameters

Factor	Inflow（L/s）	Dam shape / backwater slope gradientβ（°）	Dam height（cm）	clay content（%）	initial water content ω（%）
Value	0.5	ShapeI/10	15	5	11
	1	ShapeII/15	20	10	12
	1.5	ShapeIII/20	25	15	13
	2	ShapeIV/25	30	20	14
		ShapeV/30		30	15

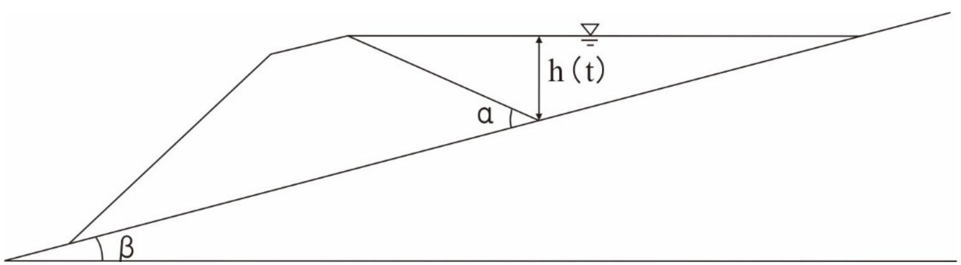
（a）Measurement of surface velocity



（b）Design of dam shape



（c）Notch size



$$V(t)=\frac{1}{2}h^2(t)[\cot(\alpha)+\cot(\beta-\alpha)]b$$

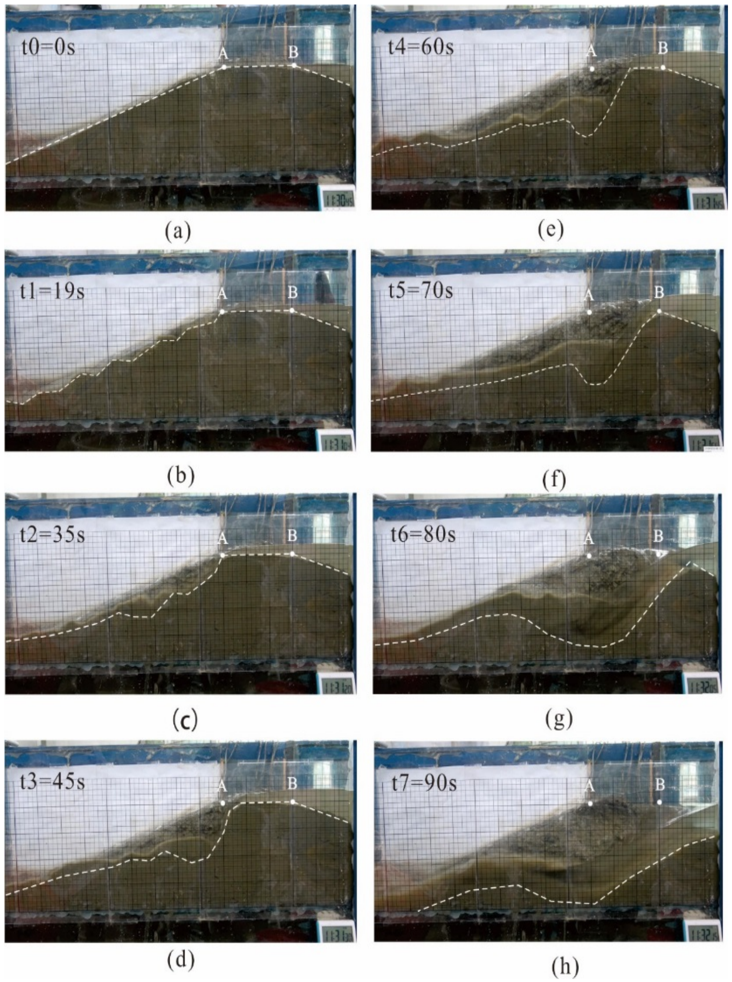
$$V(t+\Delta t)=\frac{1}{2}h^2(t+\Delta t)[\cot(\alpha)+\cot(\beta-\alpha)]\mathrm{b}$$

$$V(t)\text{-}V(t+\Delta t)=\frac{1}{2}[h^2(t)-h^2(t+\Delta t)][\cot(\alpha)+\cot(\beta-\alpha)]\mathrm{b}$$

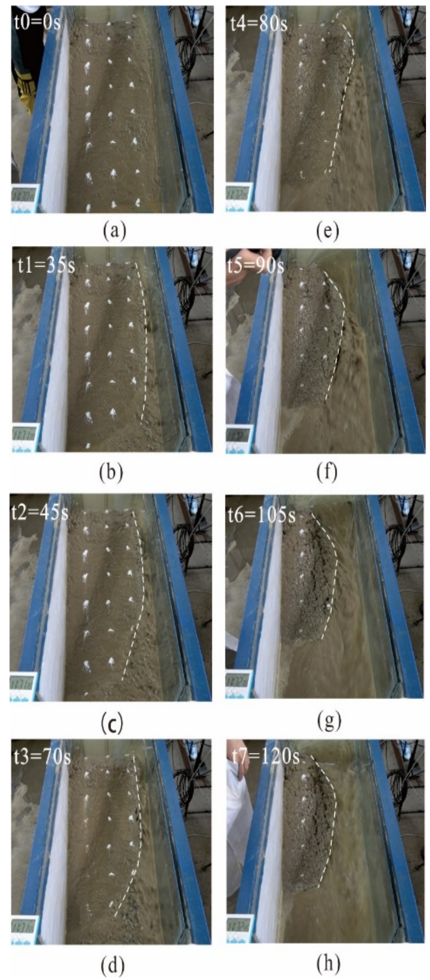
（d）Schematic diagram of dam capacity

III、Experimental result

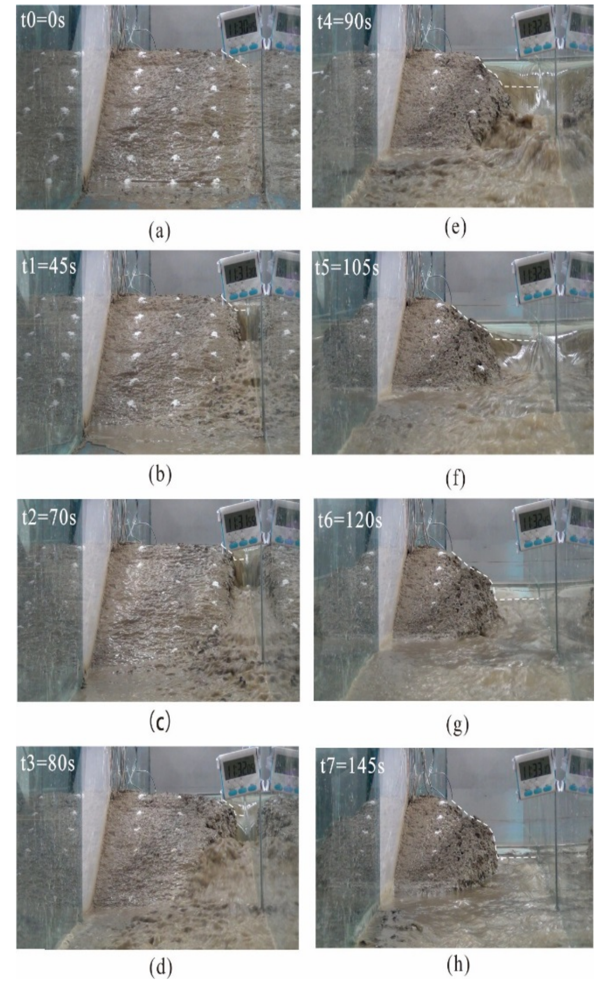
(a) Dam failure process



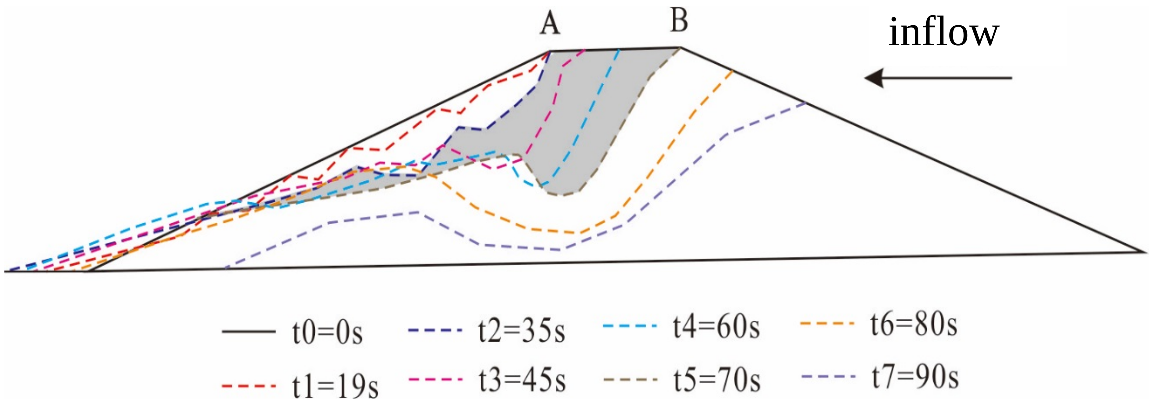
（a） Side view



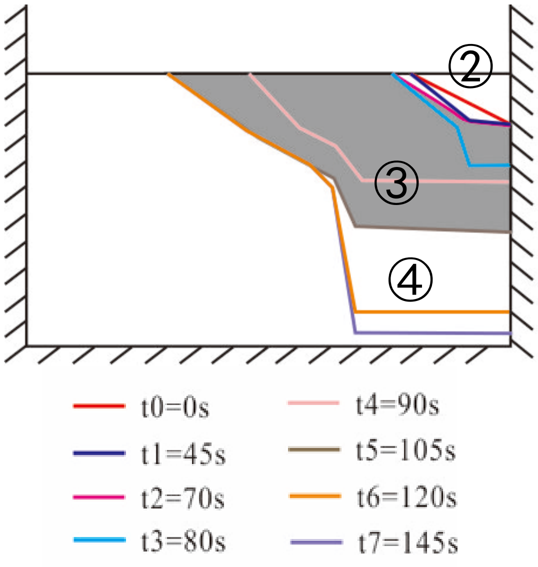
（b） Top view



（c） Front view



（a） Side view

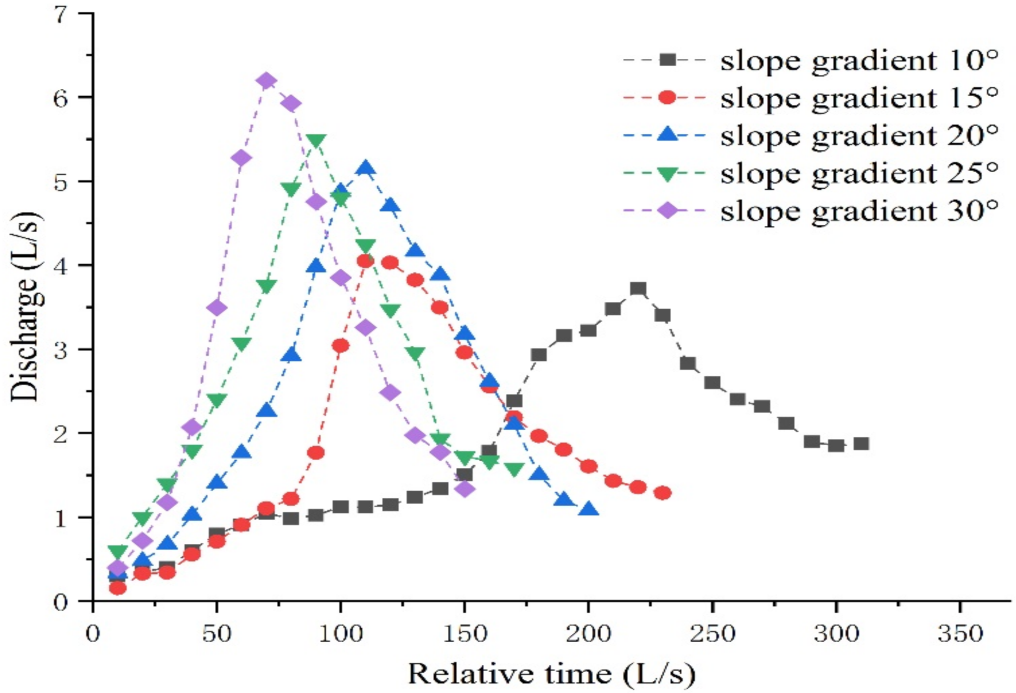


（c） Front view

- **Stage I: Slope erosion stage (0 ~ 35s)**
- **Stage II: Headcut erosion stage (35-70s)**
- **Stage III: Undercut and lateral erosion stage (70-105s)**
- **Stage IV: Recession stage (105s~ 145s)**

(b) The effect of different factors on dam failure

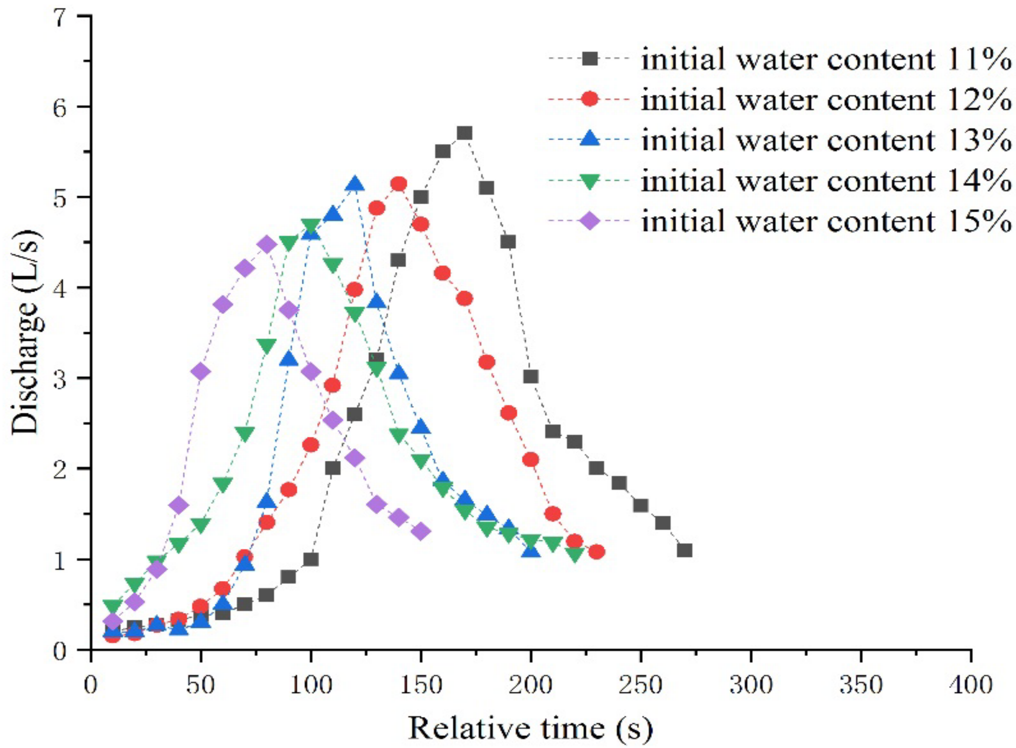
➢ **Different backwater slope gradient**



Outburst flow process under different backwater slope gradient

In the shape of dam body, the slope of backwater slope is one of the important factors affecting the flow of dam breach. The peak discharge of dam breach increases with the slope of backwater slope increasing. The discharge of dam breach at 30 ° of backwater slope is about 1.7 times of that at 10 ° of backwater slope.

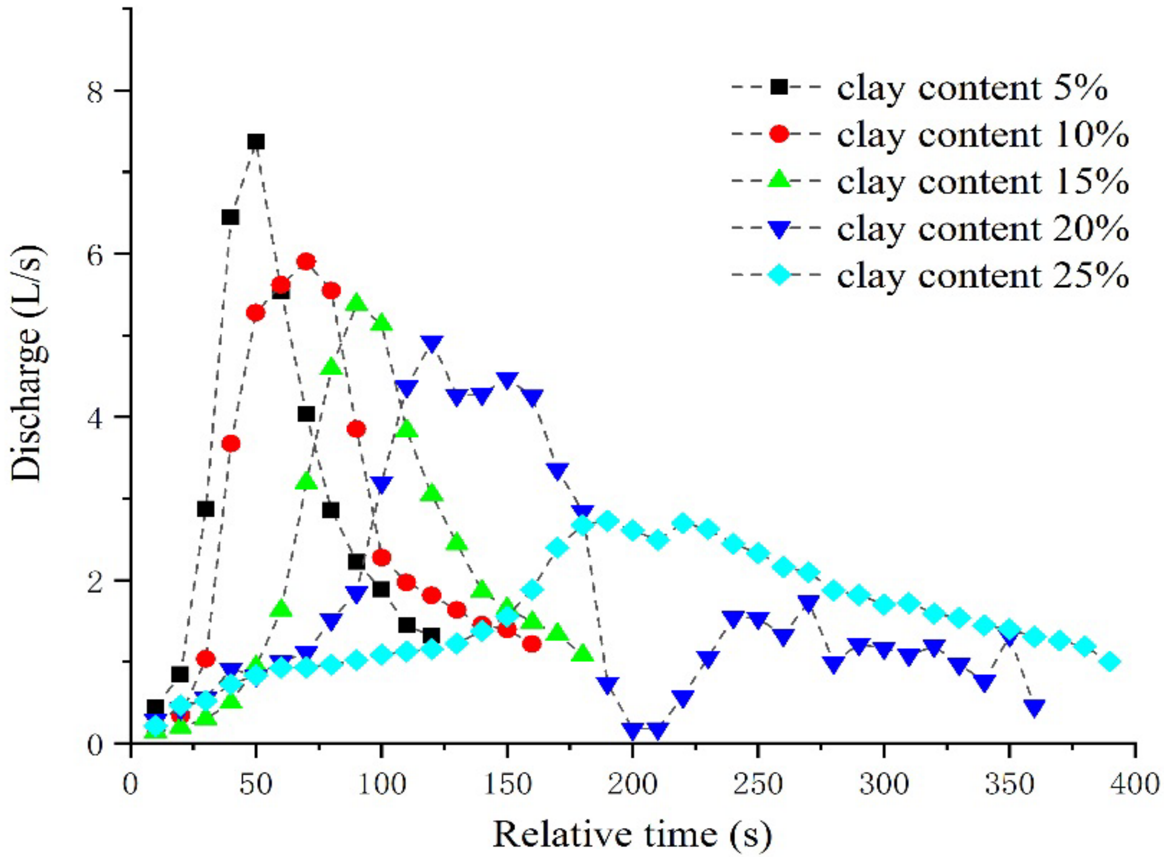
➢ Different initial water content



Outburst flow process under different initial water content

The initial water content of the soil has an important influence on the strength of the dam structure. The peak discharge of the debris flow dam break slowly decreases with the increase of the initial water content of the soil. The initial water content is negatively related to the peak discharge of the break, but the range of the change is small.

➢ Different clay content

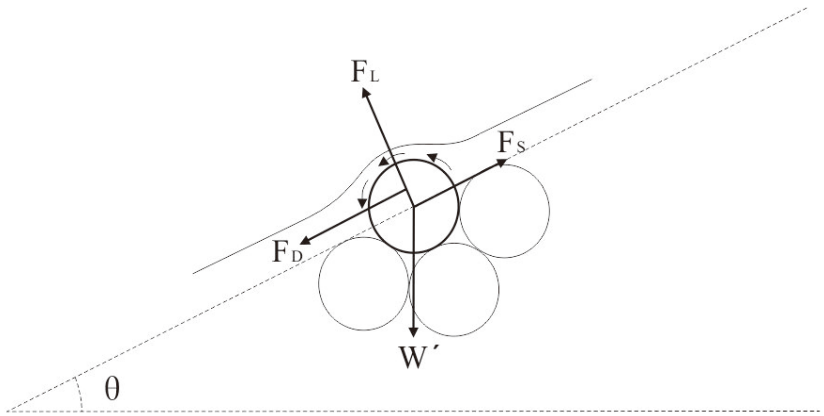


Outburst flow process under different clay content

With the increase of clay content, the burst discharge decreased rapidly, and the peak time increased rapidly. The discharge of dam breach at 5% of clay content is about 2.50 times of that at 25% of backwater slope. There was a negative correlation between the clay content and the burst discharge.

IV、Theoretical analysis

➢ Loose particles



Schematic diagram of the stress of loose particles on the slope

Drag force F_D : $F_L = a_2 C_L \dfrac{\pi D^2}{4}\dfrac{\rho u_0^2}{2}$

Lifting force F_L : $F_L = C_L A \dfrac{\rho u_0^2}{2}$

Floating gravity of particles W' : $W' = \dfrac{1}{6}(\gamma_s - \gamma)\pi D^3$

Friction resistance F_S : $F_S = (W' \cos\theta - F_L)\tan\phi$

Logarithmic velocity distribution formula near particles: $u_0 = 5.75 u_* \lg(30.2\dfrac{\chi y}{K_s})$

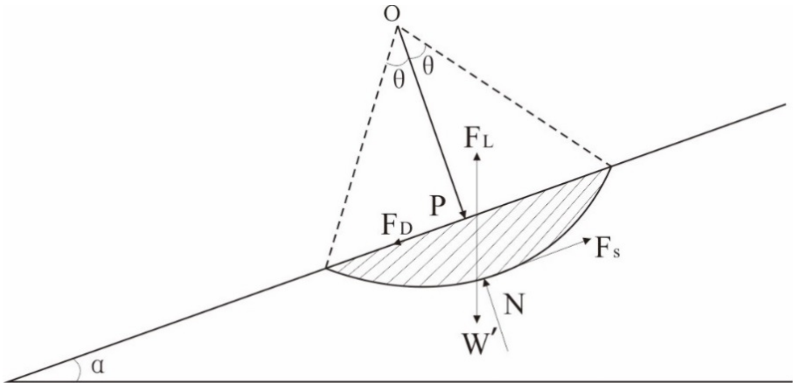
$$u_* = \sqrt{\frac{\tau_c}{\rho}}$$

Equilibrium equation: $F_D + W' \sin\theta = (W' \cos\theta - F_L)\tan\phi$

Starting conditions: $C_D A \dfrac{\rho u_0^2}{2} + \dfrac{\pi}{6} D^3 (\gamma_s - \gamma)\sin\theta \geq \left(\dfrac{\pi}{6} D^3 (\gamma_s - \gamma)\cos\theta - C_L A \dfrac{\rho u_0^2}{2}\right)\tan\phi$

$$\left(C_D + C_L \tan\phi\right) 0.75 \rho u_0^2 \geq D^3 (\gamma_s - \gamma)\left(\cos\alpha \tan\phi - \sin\alpha\right)$$

➢ Viscous particles



Schematic diagram of stress on slope surface viscous micro cluster

Drag force F_D **:** $$F_D = a_3 C_D \frac{\pi D^2}{4} \frac{\rho u_0^2}{2}$$

Lifting force F_L **:** $$F_L = a_2 C_L \frac{\pi D^2}{4} \frac{\rho u_0^2}{2}$$

Floating gravity of particles W' **:** $$W' = a_1 \frac{\pi}{6} (\gamma_s - \gamma) D^3$$

Friction resistance F_S **:** $$F_s = \xi D \left(\frac{\gamma_s}{\gamma_s'} \right)^n$$

Logarithmic velocity distribution formula near particles: $$u_0 = 5.75 u_* \lg(30.2 \frac{\chi y}{K_s})$$

$$u_* = \sqrt{\frac{\tau_c}{\rho}}$$

Torque equilibrium equation:

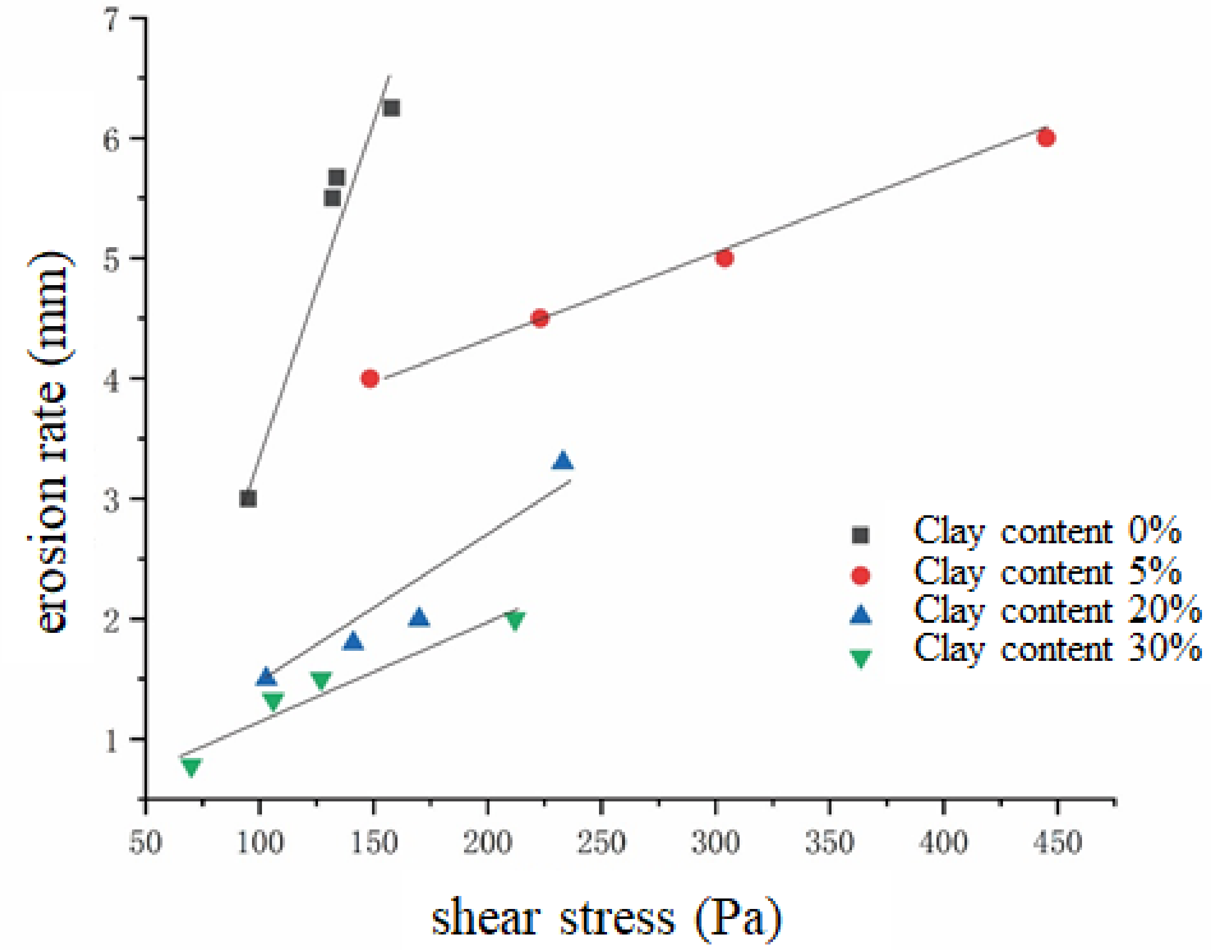
$$0 = W' L_{W'} + F_s L_{F_s} + F_L L_{F_L} + F_D L_{F_D} + P L_p + N L_N$$

$$0 = a_1 \frac{\pi}{6} (\gamma_s - \gamma) D^3 \frac{R}{2} (\sin\alpha + \cos\theta \sin\alpha) + a_3 C_D \frac{\pi D^2}{4} \frac{\rho u_0^2}{2} R \cos\theta$$

$$+ \xi D \left(\frac{\gamma_s'}{\gamma_s} \right)^n R - a_2 C_L \frac{\pi D^2}{4} \frac{\rho u_0^2}{2} \frac{R}{2} (\sin\alpha + \cos\theta \sin\alpha)$$

Critical starting shear stress:

$$\tau_c = \frac{1}{[5.75 \lg(30.2 \chi)]^2} \cdot \frac{8\xi}{\pi D (a_2 C_L \sin\alpha - a_3 C_D)} \left(\frac{\gamma_s}{\gamma_s'} \right)^n$$



By fitting and analyzing the erosion rate of landslide dam and debris flow dam in the experiment, under the same shear force, the higher the clay content, the lower the erosion rate; under the same conditions, the erosion rate of the landslide dam is the largest.

V、Conclusions

- For debris flow dam, the failure process can be summarized into four stages: Stage I: slope erosion stage ,Stage II: headcut erosion stage , Stage III: undercut and lateral erosion stage , Stage IV: recession stage.
- The effect of factors on the discharges of dam failure includes: backwater slope gradient, initial water content and clay content. The clay content is a very important factor. With the increase of clay content, the burst discharge decreased rapidly.
- Based on the torque equilibrium equation, the initiation of viscous micro cluster for debris flow dam was induced.
- By fitting and analyzing the erosion rate of landslide dam and debris flow dam in the experiment, under the same shear force, the higher the clay content, the lower the erosion rate.

Thank you

Suggestions are welcome!