XVIII World Water Congress
International Water Resources Association (IWRA)

Assessing the Risk of Earth-Rockfill Dam Failure in Cascade Watersheds: A Comprehensive Review

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第18届 世界水资源大会
水与万物:
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Introduction

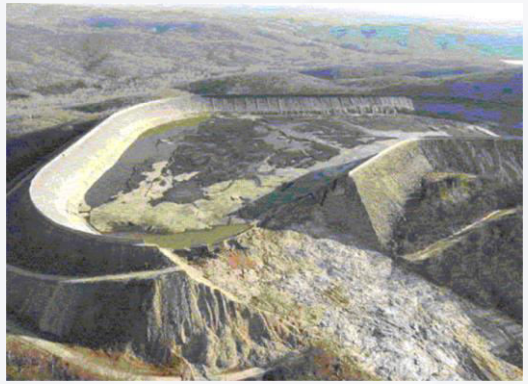
Earth-rockfill dams mainly include homogeneous dams, core dams, and face dams. They have the advantages of local materials, strong adaptability to terrain, and ease of construction. Therefore, earth-rockfill dams are commonly used in cascade watersheds to store water for hydroelectric power generation, flood control, irrigation, and domestic water supply.

However, in recent years, extreme weather events occur frequently, usually accompanied with rainstorms, landslides, mudslides and other disaster events, which seriously threaten the safety of earth-rockfill dams. The failure of such dams can lead to catastrophic consequences, including loss of life, property damage, and environmental degradation.

Lianghekou clay core rockfill dam

Chahanwusu concrete face rockfill dam

Sheyuegou core dam breached (2018.7.31)



Upper Taum Sauk dam breached (2005.12.14)

Introduction

For cascade development of reservoir group, if the outburst flood of a single earth-rockfill dam cannot be effectively retained, it may lead to sequential dam breaches, causing systemic risks in cascade watershed.

Sequential breaches of Yong 'an and Xinfa reservoirs (2021.7.18)

Sequential breaches of Edenville dam and Sanford dam (2020.5.19)

Dam breach flood inundated Midland city blocks

Therefore, it is very important to carry out risk assessment of earth-rockfill dams failure in cascade watershed, find out the possible problems of these structures in time, and guarantee their safe and stable operation to ensure the overall safety of the watershed.

Risk assessment of single earth-rockfill dam breach

Definition and representation of risk

Risk is defined as the probability of occurrence of harmful events to life and health, property resources and social environment and the severity of the consequential loss, which is expressed as the product of the probability of occurrence and the consequences, as is showed in the following formula.

$$R = P \cdot C$$

where R is risk, P is probability of occurrence and C is the consequences.

Inducements and mode of dam breach

The main inducements of earth-rockfill dam breach include flood, earthquake, seepage failure, dam slope instability, human error, etc. The dam breach mode is eventually manifested as overtopping breach.

Probability calculation of dam breach

The calculation method of dam breach probability is mainly divided into semi-quantitative analysis method and quantitative analysis method.

The semi-quantitative analysis method can adopt the event tree method, which is a time series logic analysis method and is represented by a tree diagram.

The quantitative analysis method can adopt the reliability method, mainly including first-order second-moment method, Monte Carlo method, stochastic finite element method, etc.

Risk assessment of single earth-rockfill dam breach

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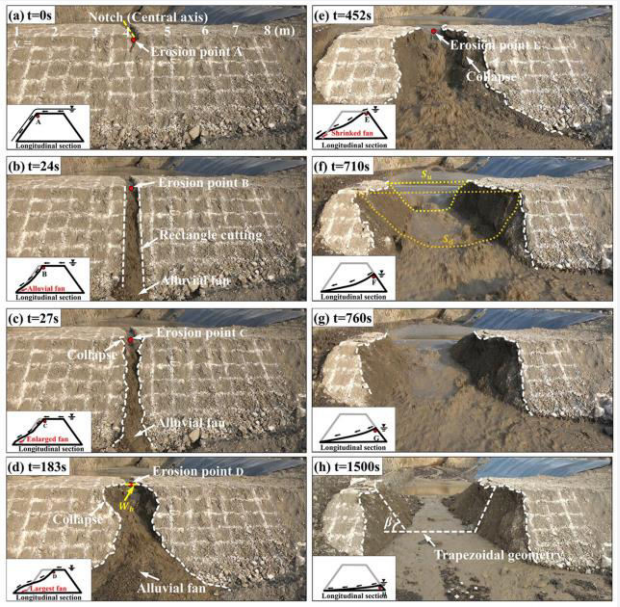
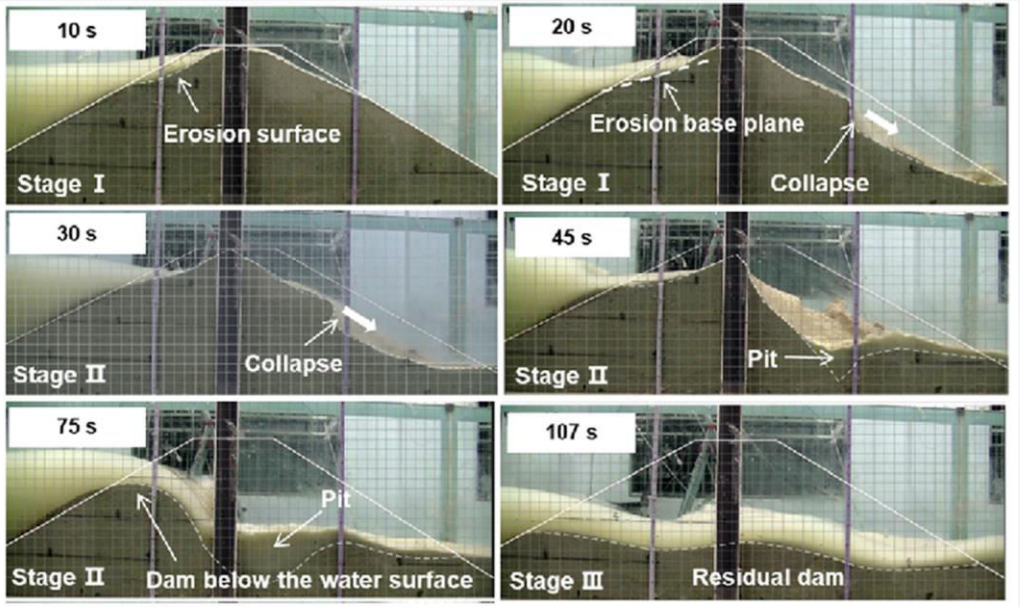
- **Investigation on dam breach process**

The breach of earth-rockfill dam is a highly complex process involving water-soil coupling and structural failure. The research methods are mainly divided into physical model tests and numerical simulation tests.

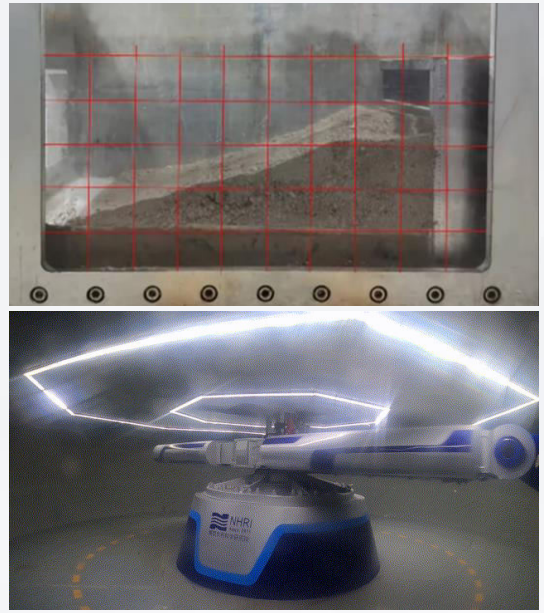
The physical model tests are divided into large-scale model tests (dam height > 1 m), small-scale model tests (dam height < 1 m) and centrifugal model tests.



large-scale model test



small-scale model test



centrifugal model test

Risk assessment of single earth-rockfill dam breach

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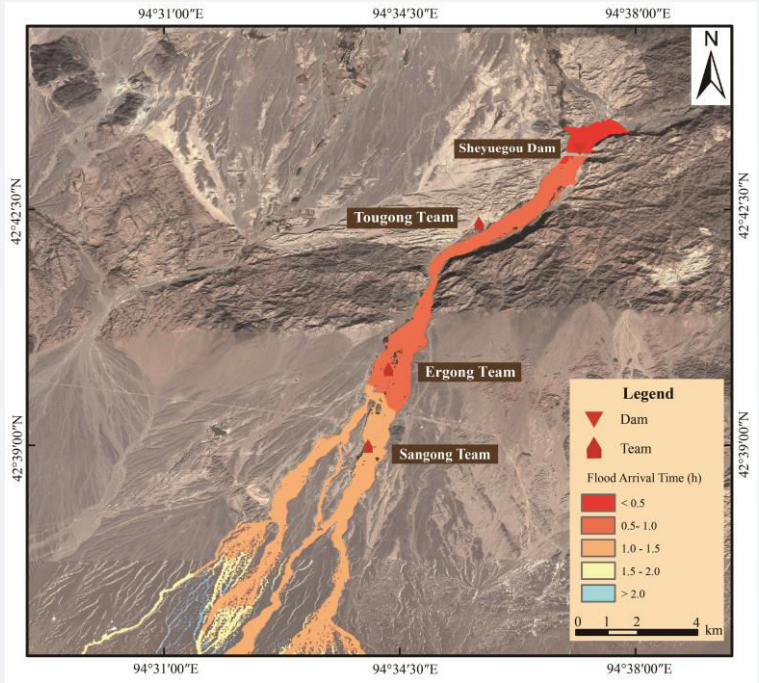
Simulation of dam breach flood routing

Based on the processing of geographic data, the calculation range is firstly determined. Secondly, one-dimensional, two-dimensional or coupled model is selected according to the characteristics of downstream terrain. Then, boundary conditions, initial conditions and model calculation parameters are set. Finally, flood routing simulation is carried out. According to the simulation results, the flood risk maps are drawn, including flood arrival time maps, submerged depth maps, flood velocity maps, etc.



flood arrival time map

Loss assessment

The consequences of dam breach flood are mainly divided into life loss, economic loss and ecological loss, which can be evaluated by establishing a corresponding Bayesian network model.

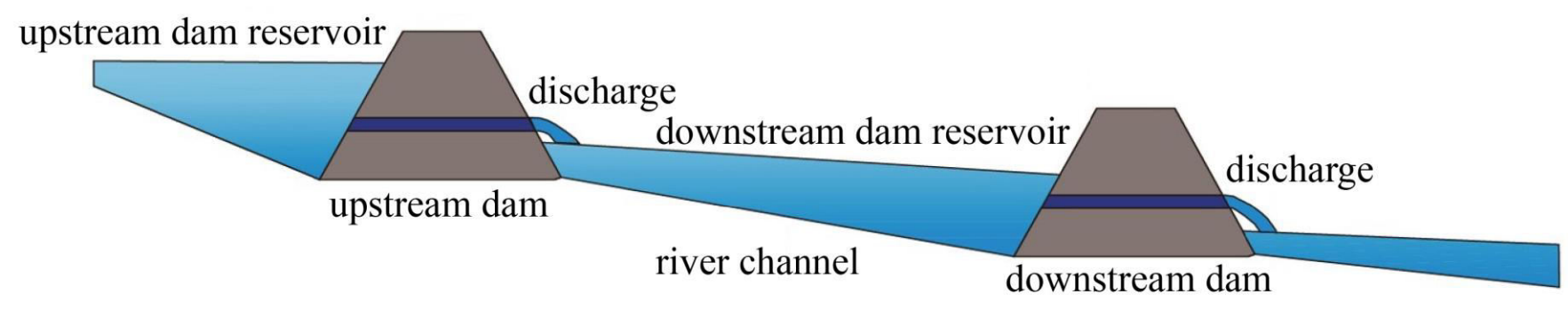
Risk assessment of single earth-rockfill dam breach

By combining the probability and loss of dam breach, the risk of single earth-rockfill dam breach can be obtained.

Risk assessment of cascade earth-rockfill dams breach

For the cascade reservoir group composed of multiple earth-rockfill dams, the cascades interact with each other and become a whole. Once an earth-rockfill dam breaches, if the dam breach flood cannot be effectively retained, it may cause chain dams breach in the downstream cascades, resulting in great risks in the entire watershed system.

- **Analysis of influence factors of sequential dam breaches**



upstream dam

- upstream flow
- reservoir capacity during dam breach
- dam breach duration
- final breach size
- ……

river channel

- length
- falling head
- slope
- roughness
- ……

downstream dam

- storage capacity between the initial water level and the dam crest elevation
- discharge capacity
- ……

Risk assessment of cascade earth-rockfill dams breach

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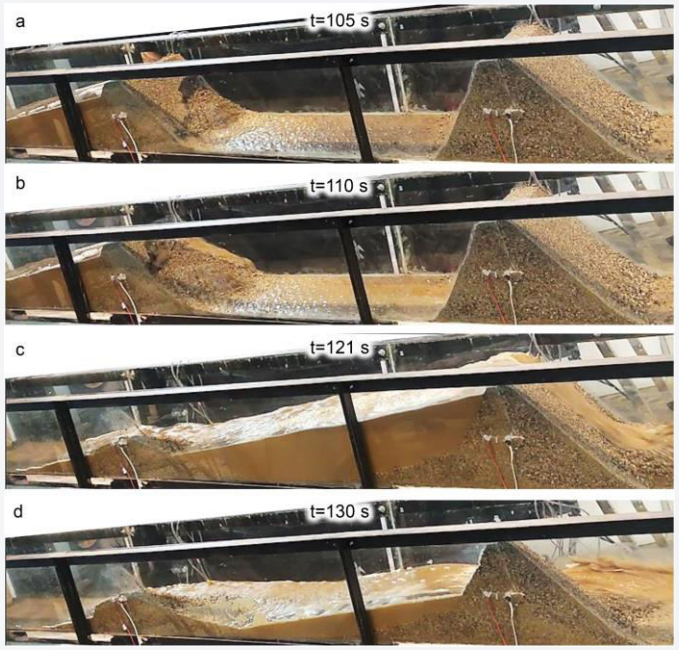
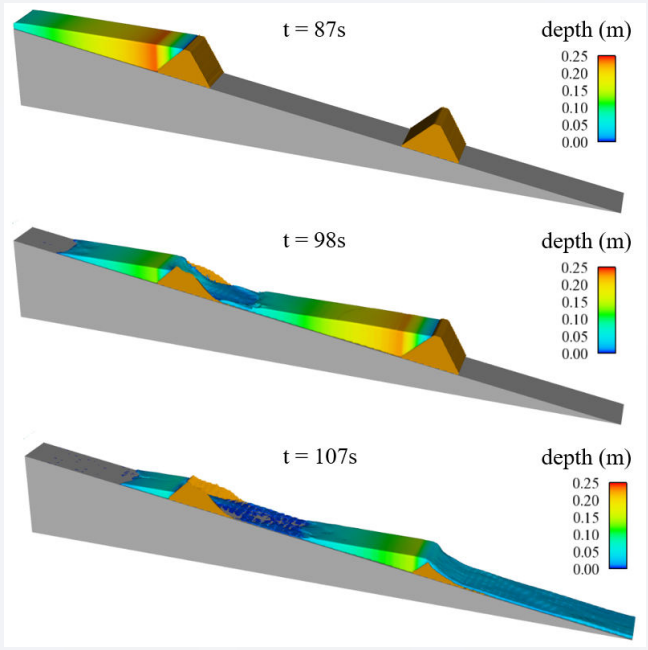
- **Simulation of cascade earth-rockfill dams breach**

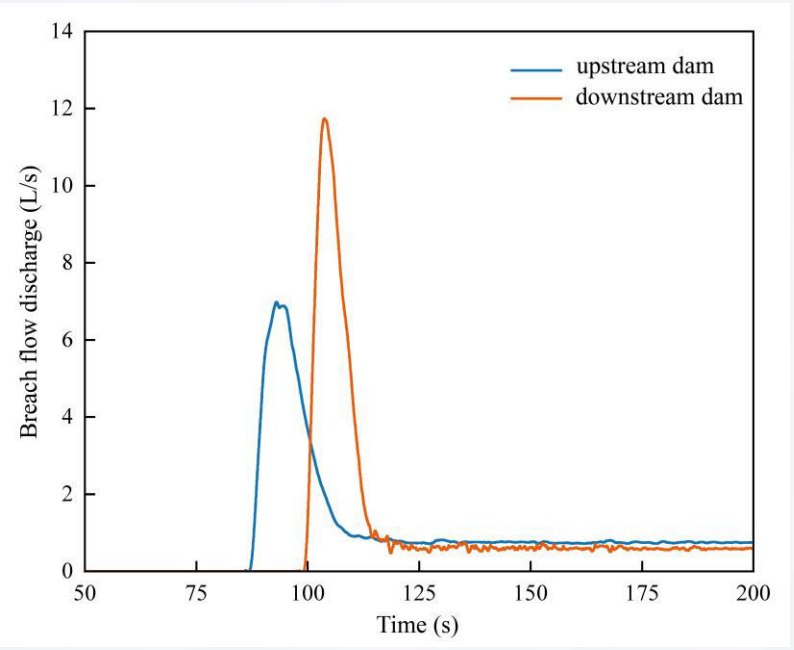
At present, the research methods are mainly flume model tests and numerical simulation tests.



flume model test



numerical simulation test



breach flow discharge process

upstream dam breach → flood routing → downstream dam breach → risk transmission and superposition

cascade amplification effect

Summary and prospects

Summary

The cascade earth-rockfill dams breach has complex mechanism, transmission and superposition effects, involving many uncertain factors. The operation and management of cascade reservoirs faces complex system risk problems. Therefore, the risk analysis of sequential failure of cascade earth-rockfill dams is of great significance to the safe operation and risk prevention and control of cascade reservoirs.

Prospects

The risk analysis of cascade reservoirs in the watershed has the characteristics of large system, complex correlation and high uncertainty. Therefore, in order to reduce the risk of dam failure of earth-rockfill dams in cascade watersheds.

- For the cascade earth-rockfill dams that have been built, joint operation and control should be made, and dam safety management and risk emergency response should be improved.
- For the undeveloped cascade watersheds, reasonable planning and design should be carried out to avoid the probability of sequential dam breaches as much as possible.