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Development Of Risk-Based Dam Safety Framework in Climate Change Condition for Batu Dam, Malaysia.

By

Wan N. H. W. Ariffin
W. N. H. W. Ariffin is with the Civil Engineering Department, College of Engineering, Universiti Tenaga Nasional, Selangor, Malaysia
E-mail: PE20813@uniten.edu.my

Lariyah M. Sidek
L.M. Sidek is with the Institute of Energy Infrastructure, Universiti Tenaga Nasional, Selangor, Malaysia
e-mail: Lariyah@uniten.edu.my

Mohammad Marufuzzaman
M. Marufuzzaman is with the Institute of Energy Infrastructure, Universiti Tenaga Nasional, Selangor, Malaysia
e-mail: M.Mohammad@uniten.edu.my

Hidayah Basri
H. Basri is with the Institute of Energy Infrastructure, Universiti Tenaga Nasional, Selangor, Malaysia
e-mail: BHidayah@uniten.edu.my

Nor H. M. Ghazali
N. H. M. Ghazali is with the Department of Irrigation and Drainage, Malaysia
email: hisham@water.gov.my

MD N. M. Noh
M. N. M. Noh is with the National Water Research Institute of Malaysia (NAHRIM), Selangor, Malaysia
e-mail: nasirnoh@nahrim.gov.my

Mohd A. Ismail
M. A. Ismail is with the Department of Irrigation and Drainage, Malaysia
e-mail: azmi@water.gov.my

Adrian M. Torres
M. Torres is with the Universitat Politècnica de València, Spain
email: adrian.morales@ipresas.com

Abstract

Dams are critical infrastructure because their failure would have catastrophic consequences for the community. for the dam owner to manage the dam's safety throughout its life cycle. However, maintaining dam safety is a challenging task as there are changes in current dam states. These changes introduce new risks to the dam's safety that were not considered when the dam was designed. A new framework must be developed to adapt to the changes in dam risk and make the dams more resilient. This study proposes a risk-based decision-making adaptation framework for dam safety management. The study focuses on the impact of climate change on hydrology because it is the primary cause of flooding and dam damage. The framework for risk analysis is adopted to enhance dam management strategies. The proposed study is divided into four phases. The first phase involves measuring the effect by evaluating the impact of climate change on embankment dams. The second phase involves analysing the potential failures of embankment dams. The third step is to analyse the various components of dam-related risks, followed by the development of a solid decision-making framework.

Keywords: Climate Change, Embankment dam, Failure, Risk-Informed Decision Making.

I. Introduction

D AM is a high-risk infrastructure as its failure is catastrophic and contributes to high damaging impacts directly and indirectly in economic, social, and environmental sectors. Moreover, as dams age and the population at the downstream area of dams grows, it will increase the risk of dam failure hazards more and more especially for a dam built in the urban and economic area [1]-[5]. Nowadays, climate change impacts are endangering water system including dam infrastructure. Therefore, a strategic approach that incorporates the current condition of the dam and the impact of future climate change should be adopted. So that the dam owner can take the correct action at the correct time and place to ensure dam safety [6]-[8].

Currently, the dam safety management practices in Malaysia are based on traditional methods. This standard framework for dam operation and management is based on the agreed design requirement which does not consider the future changes that will affect the dam safety [9]. As a result, the historical design assumption is no longer relevant for ensuring the security of the dam structure and the local community. Moreover, Malaysia as a member of the International Commission on Large Dam (ICOLD), committed to dam safety as agreed in the World Declaration on Dam Safety 2019 and Sustainable Development Goal (SDG) [10].

The use of a risk-based approach in dam safety management has increased in many countries, such as United State of America, Australia, Spain, Canada, India have adopted a risk-based approach to make dams resilient to catastrophic failure. Risk is defined as a combination of three concepts: what can go wrong (failure of critical infrastructure), how likely it is to go wrong (failure probability), and the consequences of failure (failure consequences, which include but are not limited to economic losses and loss of life) [11]. Following this definition, the risk is typically quantified in the dam safety field using the following equation [12]:

$$Risk = \int P(loads) \cdot P(response|loads) \cdot C(loads, response) \quad (1)$$

where P(loads) is the probability of the different load events, P(response loads) is the conditional probability of the structural response for each loading event, and C (loads, response) are the consequences of the system response for each loading event

Risk analysis is an appropriate methodology for assessing these risks and informing dam safety management [13]. These methods and tools can be used by any dam owner to understand the relative risks of their structures in terms of reliability, life safety, environmental impact, and third-party impacts. Risk assessment and risk management were viewed as a logical method to prioritise actions (structural and non-structural) and resources for the most benefit to the public.

In this study, the risk-based frameworks from other countries are adopted and are reviewed to suit with Malaysian scenario. The main objective of this risk-based analysis is to create a risk-informed decision-making framework (RIDM) to improve dam safety management. This risk-based dam safety management will assist the dam owner in reviewing the current dam structure integrity, current maintenance practices, and operation procedures to ensure that they comply with a current or future scenario. This will contribute a significant impact on dam safety management because the dam owner will be able to make the best decision at the right time and place. They can also use this framework to ask the government for funding to support dam services and make them more resilient to climate change. Furthermore, it will strengthen public trust, confidence, and awareness of dam safety

II. . Study Area

The location of the case study is Kuala Lumpur, the capital of Malaysia. As depicted in Fig. 1, Batu Dam is categorised as a high risk dam, because it is a large dam located in a densely populated downstream area with approximately 1.25 million population and a mixture of industry, water treatment plant, and housing scheme. Failure of the dam would likely result in widespread destruction and loss of life.

Fig. 1. *The Batu Dam, Malaysia.*

The dam was developed for the Kuala Lumpur Flood Mitigation Project in response to the 1997 flood that impacted Kuala Lumpur. The project was started with a feasibility study conducted on January 5, 1971, by the United States Department of the Interior Water and Power Resources Service project and followed by the construction of a dam which was undertaken as part of the Kuala Lumpur Flood Mitigation Project by the USBR (United States Bureau of Reclamation). The project, at cost RM 20 million, was completed in 1987. Batu Dam reservoir provides flood storage up to the 100-year frequency flood, beside the flood protection for Kuala Lumpur city center, the dam also provides sufficient supplemental water supply to Kuala Lumpur and sediment retention.

The main project components are the catchment area that covers 50.7 km forested tropical catchment and earthfill main embankment. The dam crest level is at +109.00 m, and the main dam length: 550 m with a reservoir capacity: 36.6 MCM The spillway is a side-channel inlet structure with a long crest. The outlet works include an intake structure with a multilevel intake gate and two flood control openings, an upstream conduit, a gate chamber, a downstream conduit, a control structure, and a stilling basin located at the base of the left abutment to the right of the spillway structure, as well as an upstream conduit, a gate chamber, a downstream conduit, a control structure, and a stilling basin. The outlet works supply water to municipal and industrial pipelines, and the peak inflow design flood (IDF) is 492.7m3/s for two days, 256 x 6 m3 for three days, and 21.34 x 106 m3 for four days.

The dam is constructed as a zoned earth-rockfill structure with a crest height of 39 m measured from the original ground. The dam was filled mostly using materials found locally at an estimated volume of 1.52 million m^3. The crest length is measured at 750 m which includes the berm. The crest width is measured at 10 m with the crest elevation is at 109.0 m El. The spillway is a side-channel inlet structure located at the left abutment at crest elevation El. 104.85 m. The maximum spillway discharge is 228 m3/s. Spillway structure that includes an intake structure with a multilevel intake gate and two flood control openings, an upstream conduit, a gate chamber, a downstream conduit, a control structure, and a stilling basin. The spillway's total concrete segment length is 226.53 m, with elevations varying by 44.85 m from the crest to the stilling basin invert. The spillway has a common outlet channel.

Fig. 2. *The components of Batu Dam, Malaysia.*

The outlet works are placed at the left abutment's base to the right of the spillway. The outlet works deliver water to the municipal and industrial pipeline at the control structure. The multilevel intake structure contains three 1.2 m x 2.1 m gated openings at El. 79.00 m, El. 88.50 m and El. 98.00 m to improve control of water temperature and quality for water release. The intake structure also contains two 3.75 x 3.00 m ungated openings at El. 102.70 m to provide increased capacity during flood releases.

III. Proposed Methodology

This study was mainly focused on determining out how much of a risk there is based on how climate change affects the water load, reservoir routing, and the effects of failure. To do this, the approaches should be applied to the current situation and the future load that will be caused by the effects of climate change. This will help dam owners make decisions based on accurate information. In this study, the following time frames are suggested:

- Period 1: 1970-2019.
- Period 2: 2020-2039.
- Period 3: 2040-2069.

- Period 4: 2070-2099.

Fig. 3 is a flowchart of the proposed methodology. This research project engages four main stages. All required data, such as rainfall, runoff, design report, operation dam records, storage, spillway, and inspection report, are obtained for review.

Phase 1: Assess load of the system: The first phase of this proposed work is to assess the hydrological load of the system. The historical rainfall data from the nearby station at the study area used to extract climate change projections rainfall data by using Global Climate Modes (GCMs) downscaling.

Then, the Probable Maximum Precipitation (PMP) will be analysed to generate Probable Maximum Flood (PMF) hydrographs through using HEC-HMS hydrological model, which is configured based on the basin's physical characteristics and hydro-meteorological observations. The results from PMF inflow hydrographs arriving into the reservoir were used to simulate the dam failure and breach process by using MIKE 11 at loading scenarios that are characterized by three initial operation water pool levels. which is minimum operation level (MOL), normal operation level (NOL) and maximum operation level (MXL).

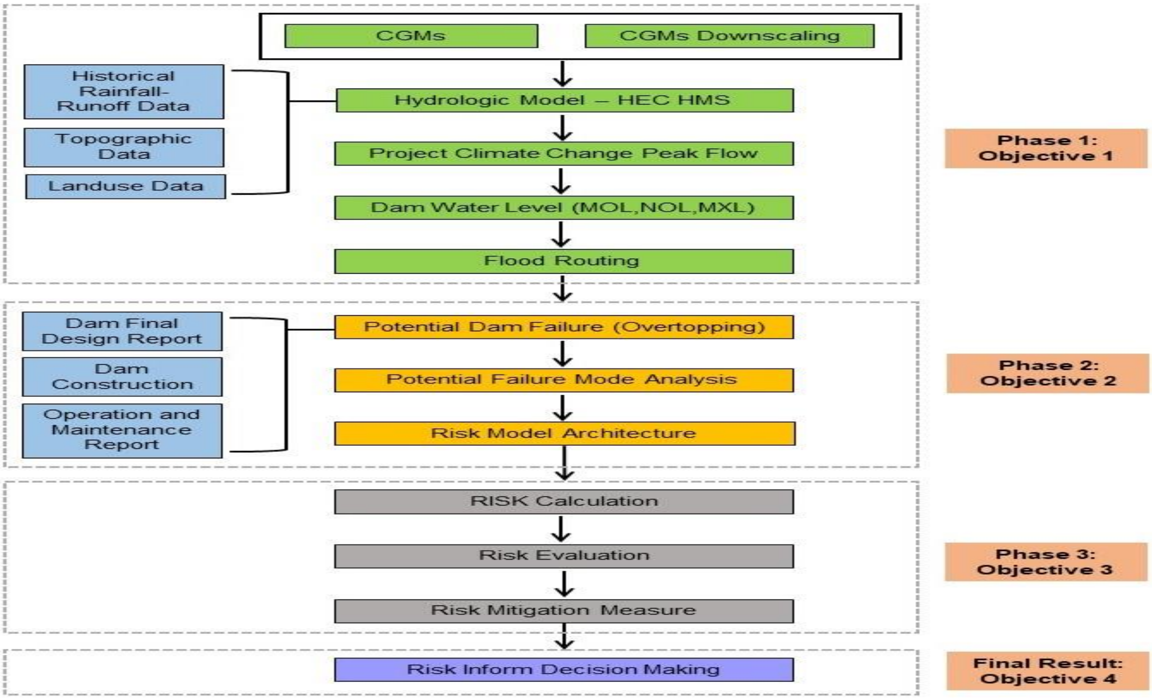

Fig. 3. *Proposed RIDM Framework for Batu Dam, Malaysia.*

Phase 2: System Response. Potential dam failure will access through the Potential dam Failure Mode Analysis (PFMA) workshop. The workshop will be conducted with all of the experts and the dam owner to review and analyse the dam's design, construction, and historical performance. The entire PFMA will be used to identify the risk adaptation measure. The safety planning and risk reduction programme can be implemented. This will assist the dam operator in concentrating the surveillance and monitoring on the specific failure and performance parameters [14].

Then, the probability of failure will be calculated using event tree analysis to assess the likelihood of dam failure as a result of climate change. This provides a foundation for defining appropriate structural and non-structural risk mitigation steps.

The final step in this phase is to quantify the consequences. MIKE 21 will be deployed to generate flood hydrographs, and MIKE FLOOD will be routed downstream to estimate the resulting inundation maps. This data is used to calculate the consequences curve in peak discharge at current development and forecast future land uses.

The consequences of potential failure assessed that directly and indirectly affected by the failure. Calculation of direct consequences due to inundations is dependent on two factors: exposure, which refers to the presence of people in an at-risk area; and vulnerability, which refers to how easily they can be impacted [15], [16]. To estimate indirect costs as a percentage of direct costs, a fixed percent could be applied to the costs depending on the climate change scenarios [17], [18].

Phase 3: Risk Analysis: In the next phase, the framework will evaluate and prioritize potential failure by probability risk analysis. The risk model architecture is shown in Fig. 4.

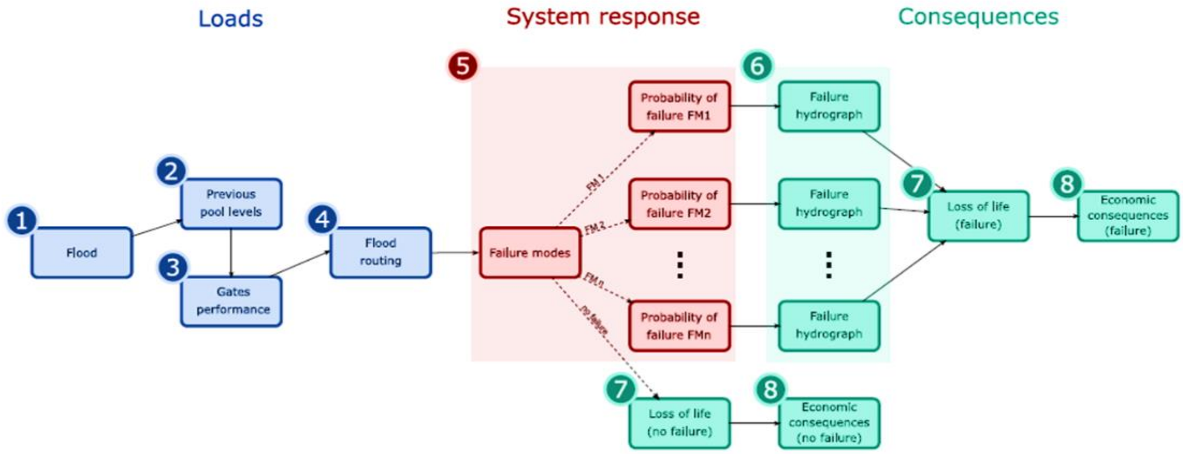

Fig. 4. Risk *Model Architecture in RIDM framework [19]The dam's risk model will be set* up with *iPresas software, developed by the Valencian Technical University, which uses different hazard* mechanisms *for each hydrological loading scenario. Models of this kind were constructed using event trees, a strategy that can account for all the possible chains of events that might lead to a dam failure [20]. Then, the Quantitative risk analysis (QRA) will be done. The comprehensive QRA will be conducted to inform the prioritization of security investments in infrastructure assets and portfolios.*

Phase 4: Framework for Risk-Informed Decision Making: Ultimately, the risk informed decision-making framework will be addressed. This framework will improve current dam maintenance and operation practices and Standards to ensure dam safety and resilience to **climate change**

Conclusion

The proposed research framework would help the dam owner to take the most effective action to ensure the dam's safety in future climate conditions. Beside that it can be used to evaluate the dam's performance in order to aid future inflow forecasting decisions. Moreover, the framework will improves the effectiveness of reservoir operation and planning. This research may stimulate long term efforts to increase government investment in dam safety and public awareness of dam safety.

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