

A literature review on dam break analysis

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Abstract

The process of dam break analysis is explored in the form of three steps based on the available literature in the present work: the assumption of dam failure, routing the flood wave generated, and assessment of areas affected by dam break. Dam failure is essentially considered in the form of a breach, which is dependent on various factors. However, in the process of dam break analysis, the breach assumption can be based on the existing empirical equations suggested by researchers or based on physical models. The assumed dam failure gives rise to flood wave generation, which is routed further downstream of the dam section. Various hydraulic models that can be effectively applied to flood routing are available. The results of flood routing can be applied to estimate the risk potential of such flooding scenarios. The time of arrival of the maximum flood and the flood water flow in terms of depth and velocity at a given location downstream for the assumed dam failure play an important role in assessing the damage potential of flood due to dam break.

Key Words: Dam break analysis, Breach parameter estimation, Flood routing

Introduction

Dams are important elements in the field of water resource engineering. These are structures that serve various purposes, including water storage, flood control, and hydroelectric power generation. Considering the functionality served by dams, it is evident that proper quality control during the execution and safety of the structure during its expected life should be ensured. Considering the advancement and the level of development of water resource management in countries such as India, we are at a stage where almost all major schemes of dam construction have been accomplished, and this necessitates the provision of proper inspection and maintenance of dams with reference to dam safety. Considering the term dam safety, the process of dam break analysis has been identified as an essential study for any given dam. Such a study can help decision makers identify the areas to be prioritized during a catastrophic dam failure event. This paper summarizes the state-of-the-art dam-break analysis process. The process of dam break analysis essentially consists of three steps: first, the assumptions of dam failure and selection of

breach parameters, the second step is routing the generated flood wave resulting from the dam breach downstream of the dam section, and third, the assessment of the affected areas inundated due to flooding.

1. Assumptions regarding dam failure

The assumption of dam failure is the most crucial part of dam break analysis. (Xiong 2011) identified the process of estimating breach parameters as one of the crucial steps in carrying out dam break analysis. A widely accepted approach for breach parameter estimation is the use of empirical equations suggested by various researchers. Whal (1998) documented various breach parameters and empirical equations suggested by various researchers, based on historical dam failures.

Some of the common empirical models include Froehlich's equations (2008, 2016), USDA SCS (1981), Simplified Triangular Breach, MacDonald & Langridge-Monopolis (1984), and Van Thun and Gillette (1990). Among various empirical models for calculating breach parameters, the equations suggested by Froehlich (2008, 2016) have been recognized as the most appropriate in most of the literature. The same has also been suggested in the DRIP manual by the Central Water Commission, India. Dhiman S et al (2019) has compiled a list of Indian dam failures, using data from government reports, articles, news, and magazines, to develop breach parameter equations. New empirical equations were proposed for breach parameters and peak outflow by incorporating variables such as dam height, reservoir capacity, and erodibility. These equations were compared with existing equations to improve the prediction of breach parameters and peak outflows. It has been identified that the equation suggested by Froehlich (2008) provides the best result as per the available dam failure records in India. The assumption of the breach parameter significantly influences the breach outflow hydrograph and ultimately the damage potential of the resulting flood.

Another approach to breach parameter estimation is a physical or process-based model that simulates the actual breach process using soil properties and hydraulic conditions. These models model the interaction between the hydraulic forces and the geotechnical erosion process. Unlike empirical equations, this approach is not based on historical failures but rather on the principles of fundamental physics. Some popular models in this approach are HR BREACH (HR Wallingford), WINDBRO (USACE 2009), and BEED (Bureau of Reclamation). The major limitation of the process-based approach is the limitation in available data on soil properties, which necessitates a comprehensive geotechnical investigation and leads to the complexity arising from the simulation of such processes. The calibration and validation of such an approach is also difficult.

1.1 Various works highlighting the breach parameters

Macchione et al. (2016) evaluated dam breach modeling approaches by comparing parametric models in HEC-RAS with a simplified physically based model (Macchione, 2008) to predict downstream flood impacts and found that the physically based model (with

minimal calibration) outperformed parametric models in predicting downstream water levels, reducing uncertainties tied to empirical parameters; however, the study was based on a single case study of Big Bay dam failure.

Gaagai et al. (2021) modeled dam-break flooding risks for the Yabous Dam (NE Algeria) using 1D HEC-RAS and analyzed breach parameters (width, slope, and formation time) via sensitivity analysis. The study has identified that breach width and slope significantly influence flood wave dynamics, while formation time has an inverse effect, and that Froehlich's methods are reliable for breach parameter prediction.

Khalkho et al. (2020) simulated a hypothetical piping failure of the Adwa dam in Mirzapur, Uttar Pradesh, India. This study identified the effectiveness of the HEC-RAS model for such a study, and the breach parameters were based on Froehlich's method.

2. Routing the flood wave

The typical process of dam-break analysis involves the routing of flood waves generated because of the assumed dam failure. The modern computing platform integrated with GIS promises an efficient flood-routing process. Some of the widely used models for flood routing include HEC-RAS, MIKE11, and FLDWAV.

2.1 Various works highlighting the flood routing models in dam break analysis

Hosseinzadeh-Tabrizi, S. et al (2022) has employed 2D HEC-RAS model to simulate dam-breach flood scenarios (piping vs. overtopping) for Iran's Sattarkhan Dam. These findings highlight vulnerabilities in downstream regions and advocate for preventive measures in flood-prone zones. This work also highlights the effectiveness of HEC-RAS in effectively carrying out such studies.

Kumar et al. (2017) reviewed the existing literature on dam-break studies and inundation mapping using hydraulic models and GIS. The various hydraulic models identified in this study are presented below:

Table 1: Some of the hydraulic models for dam break analysis

Model	Description	Key Features
DAMBRK	Predicts dam breach wave formation and progression.	Describes dam failure modes, computes outflow hydrograph, routes outflow.
FLO-2D	Predicts flood hazard, mudflow, and debris flow.	Uses grid system, determines floodplain based on elevation and roughness, models sediment flow.
FLDWAV	Predicts rapid flood events.	Has wave front tracking, calculates potential affected area, models flow through stream networks.
SMPDBK	Simplified version of DAMBRK.	For dam classification and risk, quick and easy to use.

MIKE 11	1D tool for simulating flood waves, sediment transport, water quality.	Modular structure, simulates unsteady flow.
MIKE 2	2D modeling software for free surface flows.	Simulates flow in rivers and estuaries, predicts floodplain situations.
HEC-RAS	Simulates flow in river channels and floodplains.	Performs 1D and 2D hydrodynamic unsteady flow routing, models dam break.

Karam W et al (2021) simulated the dam-break flood of Pakistan's Attabad Lake (formed by a 2010 landslide) using the 3D CFD model FLOW-3D to predict peak flow depths, velocities, and inundation extents identifying the vulnerable areas, emphasizing the need for emergency plans.

Kulkarni. S et al. (2016) analyzed the potential dam-break effects of India's Pawana Dam using empirical methods (the Froehlich equation) and ANSYS Fluent CFD simulations to estimate breach discharge and downstream flood impacts. The results identified nine high-risk villages (e.g., Phagne and Kale) along with rehabilitation costs. This study emphasizes preventive measures (e.g., dam safety reviews) over costly post-disaster rehabilitation. Key recommendations include regular monitoring and emergency planning to mitigate life and economic loss.

Goharnejad et al. (2016) simulated the embankment dam break of Iran's Taleghan Dam using Flow-3D software and empirical equations (Froehlich, MacDonald) under five flood volume scenarios (5–25 MCM). As per the study, numerical models aligned closely with empirical methods (4–74% error), validating their reliability, especially for large inflows. The RNG turbulence model effectively captured dam erosion and breach dynamics. Findings emphasize Flow-3D's utility in predicting dam failure impacts for flood risk management and emergency planning.

Najar. M et al. (2022) examined the influence of dam breach parameters on flood hydrographs using five common breach prediction methods and a 2-dimensional HEC-RAS model. Ürkmez Dam was used as a case study because of its potential risks to downstream populations. This study investigated various reservoir storage levels and conducted a sensitivity analysis to assess the impact of breach parameters on flood hydrographs. The results indicate that the Froehlich approach is the most reasonable approach for estimating dam breach parameters. Key findings highlight that breach time formation significantly affects peak discharge and time to peak, whereas the breach-side slope has minimal influence.

3. Assessment of the affected area due to dam break

The third step in the process of dam-break analysis generally refers to the interpretation of the results of flood routing of dam-break waves. This analysis can have various aspects, including the time of arrival of the flood along with the depth and velocities at various critical locations downstream of the dam. The damage associated with a flood has a direct correlation with the depth of the flood at a given location. Various studies have been conducted to identify various aspects of

flood-affected areas for a given flood event. The various hydraulic models discussed in the previous sections provide results in the form of flood depth, velocity, and time of arrival. The hydrographs generated in various areas of interest also provide substantial information necessary for mitigating the adverse effects of floods. Cox et al (2010) in the document ‘The Australian Rainfall and Runoff Revision Project 10’ establishes safety criteria for people in floodwaters, focusing on depth-velocity thresholds. Key findings include the relationship between the product of depth and velocity, and the level of hazard for various categories. The category is defined based on the products of height and mass. Category 1 included Infants, Small Children ($H.M \leq 25$), and frail or older persons. Category 2 included children ($H.M = 25-50$) and category 3 included adults ($H.M > 50$).

Table 2: Flow Hazard Regimes for Infants, Children, and Adults

$D \cdot V$ (m ² /s)	Category 1	Category 2	Category 3
0	Safe	Safe	Safe
0 – 0.4	-	Low Hazard	-
0.4 – 0.6	-	Significant Hazard; Dangerous to most	Low Hazard
0.6 – 0.8	Extreme Hazard; Dangerous to all	-	Moderate Hazard; Dangerous to some
0.8 – 1.2	-	Extreme Hazard; Dangerous to all	Significant Hazard; Dangerous to most
> 1.2	-	-	Extreme Hazard; Dangerous to all

The above study has also been cited in the DRIP manual ‘Guidelines for Mapping Flood Risks Associated with Dams,’ published by the Central Water Commission, Government of India. The above guidelines can be successfully applied in dam break analysis to identify the level of hazard at a given location. If GIS-based population data are available downstream of the dam, hazard maps can be generated and used for emergency action planning.

Conclusion

The process of dam break analysis is essentially based on the assumption of breach parameters, which are dependent on either process-based models or empirical models suggested by researchers. In any case, the actual failure may or may not take place according to the assumptions; however, the existing literature suggests that Froehlich’s equations (2008, 2016) are well suited to the Indian conditions for the process of dam break analysis. Hence, for the Indian scenario, these equations can be successfully applied to aid in emergency action plans. Among the various hydraulic models available for flood routing, the HEC-RAS model has been widely applied and cited for the process of dam break analysis because of its robust nature and availability for use. Furthermore, the guidelines laid by Cox et al. (2010) can be effectively applied to the assessment of areas affected by dam-break flood waves. It is important to note

that the dam-break analysis process is divided into three sections. These steps can be applied to any dam to create a database that may aid in emergency action plans and policy makers in making decisions in times of catastrophic dam failures.

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