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CONTENTS

Assessing flood inundation for breach of Jamrani Dam, Uttarakhand using HEC-RAS 2D

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ABSTRACT: A dam is a construction designed to retain surface water, raising its level to ensure its availability for various needs. It serves multiple purposes, such as supplying water for irrigation, domestic and industrial use, aquaculture, and navigation. Additionally, dams effectively mitigate the risk of downstream flooding by securely containing excess water behind their walls, preventing potential destruction to lives, infrastructure, the environment, and the surrounding landscape. The present aim is to prepare a 2D model to carry out a dam breach analysis for overtopping failure of the Jamrani dam. The goal is to generate flood depth, velocity and breach outflow at various locations such as Kathgodam, Haldwani, Lalkuan and Kichha and generate an inundation map. To accomplish this objective, the dam breach model is developed using HEC-RAS software and RAS Mapper is utilized to produce a flood inundation map. To simulate the most extreme scenario, the unsteady flow condition incorporates the use of the probable maximum flood (PMF). Further, the flood wave is routed using the diffusion wave equation. The maximum breach flow produced at the locations downstream of the dam is 66283.22 m^3/s and the maximum area inundated is 464 km^2 for overtopping failure. Ultimately, this study aims to assist relevant authorities in formulating an emergency response plan and implementing effective measures to mitigate the impact of flooding.

Key words: HEC-RAS, Jamrani, two-dimensional, modelling

Dams offer numerous advantages to our society; however, the catastrophic calamities caused by dam failures and subsequent floods have been among the most devastating disasters witnessed in the past 200 years. It is vital to simulate dam breach incidents and their resultant floods to comprehend and mitigate the risks associated with potential dam failures, thereby enhancing our ability to safeguard against such threats (Xiong, 2011). Based on the material used in construction dams are classified as embankment dams, concrete dams, and masonry dams (Zhang *et al.*, 2015). The dam in this study i.e., Jamrani dam is roller compacted concrete gravity dam. Dam break is uncontrollable breach causing significant impacts on the surrounding land and downstream communities (George and Nair, 2015). According to central water commission, until 2018, approximately a quarter of all reported dam failures were attributed to overtopping failures. In dam break modelling, there are two primary tasks: forecasting the hydrograph of the outflow resulting from the dam breach and creating the maps that depict the areas affected by flooding (Wahl, 1997; Ackerman *et al.*, 2008).As the Manning's value increases at the site, there is a corresponding decrease in the flow value at all locations downstream of the Baur dam (Ramola *et al.*, 2020). Breach width is an important characteristic for the dam breach. Peak flow is significantly affected by the breach width (Singh *et al.*, 2022). The main goal of this study is to conduct a dam breach analysis for the Jamrani dam, aiming to forecast key characteristics of the resulting flood wave, such as the peak flood discharge, stage, timing of the peak flood occurrence, and routing of the peak flood at downstream of the river. The failure mode adopted for the analysis is overtopping. Overtopping failure causes more severe damages downstream than piping failure (Ramola *et al.,* 2019, 2021). Additionally, inundation map has been created for the scenario.

MATERIALS AND METHODS

Study Area

The Jamrani Dam is proposed to be built on the Gola River, upstream of the existing Gola barrage, about 10 Km upstream of Kathgodam in Uttarakhand's Nainital district. It will be standing 150.60 m high after construction. It is a roller compacted concrete gravity dam. The dam's latitude and longitude are 29°16'15" N and 79°36'36"E, respectively. The project structures, including the reservoir area, are in the Uttarakhand district of Nainital.

The catchment is well dissected by numerous streams and the main drainages are Kalsa River, Gola River and Lugar Gad. The relief varies between elevations 635 m and 2286 m. The Gola River is a flashy seasonal river having a catchment area of 450 km^2 up to the dam site. It originates in the Kumaon Himalayas and flows through the state of Uttarakhand, India. It is primarily fed by runoff generated during the monsoon season when discharges are high but gradually decrease during the drier season. The length of the dam crest is 480 m, and the gross storage capacity is 208.60 MCM. The stored water will be used for power generation through 14 MW installed capacity powerhouse. Since it is a proposed dam, it is important to analyze and plot a flood inundation map of the proposed dam. The location of the dam is show in the Figure 1.

This study involves preparing a model of the Jamrani dam and estimating the flood hydrograph at the dam location and plotting a flood inundation map of the dam breach due to overtopping. The tool used for making the model is HEC-RAS 6.3.1 and RAS-Mapper is used to plot the flood inundation map.

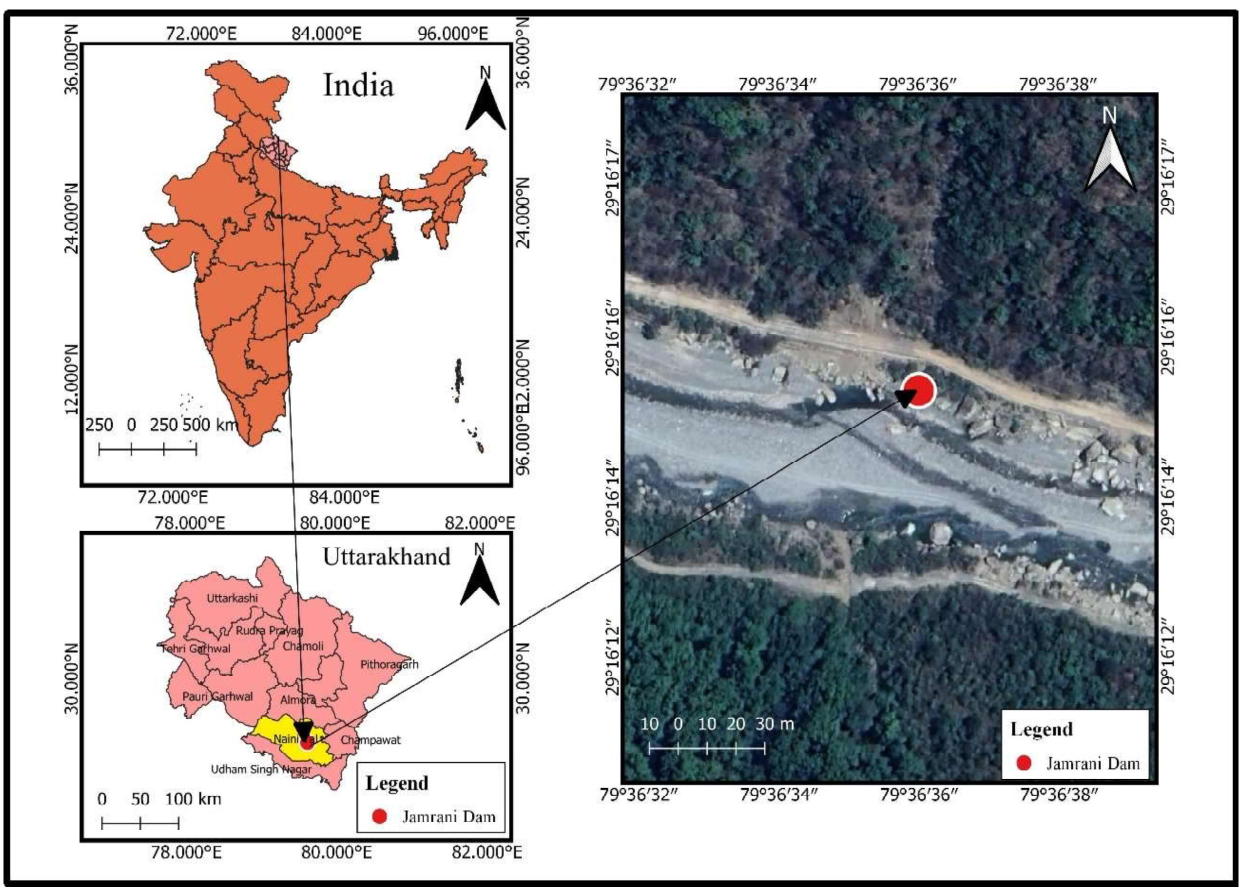

Fig. 1: Study area

HEC-RAS uses 2D Saint Venant's equation for flood routing at downstream after the dam breach. The 2D Saint Venant's equation can be obtained from Reynold Navier Stoke's equation by depth averaging method and assuming hydrostatic pressure distribution and small channel slope. This is suitable for flow over Dykes and the floodplain. The 2D Saint Venant's equation is as follows: -

Conservation of mass

$$\frac{\partial h}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0 \quad (1)$$

Conservation of momentum

$$\frac{\partial (hu)}{\partial t} + \frac{\partial (hu^2+0.5gh^2)}{\partial x} + \frac{\partial (huv)}{\partial y} = 0 \quad (2)$$

$$\frac{\partial (hu)}{\partial t} + \frac{\partial (hv^2+0.5gh^2)}{\partial y} + \frac{\partial (huv)}{\partial x} = 0 \quad (3)$$

Where,
h = water depth
u and v = horizontal velocities average over vertical direction

The methodology adopted for the dam breach analysis is shown in Fig. 2. Following sections explain in detail the steps in hydraulic modelling and flood plain mapping.

Geometry

The fundamental necessity for hydraulic modelling is the knowledge of the river's shape and structure. This information can be obtained through either on-site surveys or remote sensing data. Although traditional survey techniques provide precise river geometry, they are laborious and time-consuming, especially when dealing with large areas. Conversely, remote sensing data offers a more efficient and cost-effective alternative, leading to its increased utilization in hydraulic modelling. In this particular study, the Cartosat-1 Digital Elevation Model (DEM) with a resolution of 30 meters (source: ISRO Bhuvan) is employed. This DEM is subsequently transformed into a terrain model to incorporate other geometric aspects relevant to the dam.

In HEC-RAS, the reservoir can be represented using two different approaches. The first approach involves modeling it as a storage reservoir with a storage-elevation relationship, leading to level pool routing. The second approach involves representing the reservoir using 1D cross-sections spread across its entire pool, resulting in dynamic flood routing. Since a two-dimensional approach is used, storage reservoir is modeled using storage-elevation relationship leading to a zero-dimensional modeling. The elevation-capacity curve is shown in Figure 3.

2D flood plain and Dam modeling

The most recent version of HEC-RAS 6.3.1 now includes the capability to perform two-dimensional flow routing in which downstream region can be modeled in three different ways.
To establish a connection between storage areas and 2D flow areas dam is modeled as surface area 2D connection.

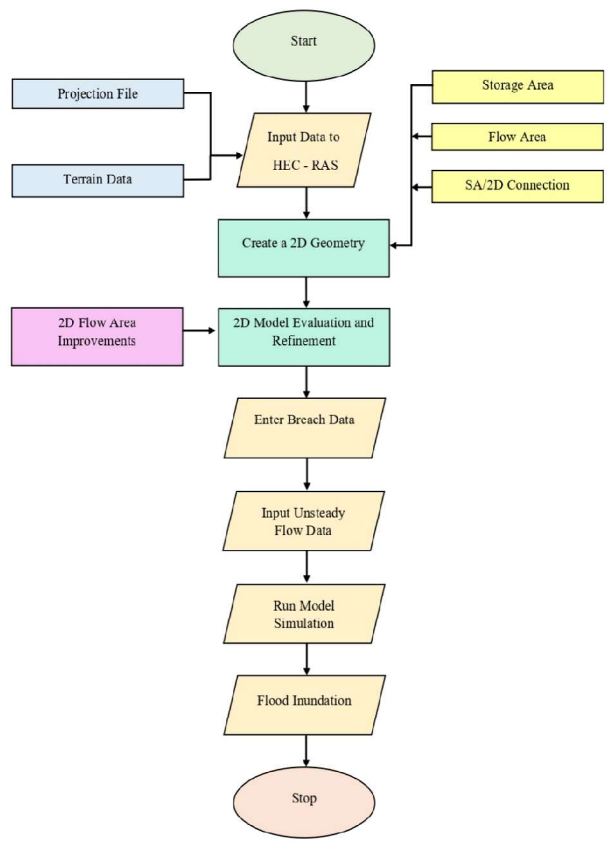

Fig. 2: Flow Chart

Table 1: Breach parameter selection criteria

Dam Type	Average Breach Width	Horizontal Component of Breach Side Slope (H)H:1V	Failure TimeTf (hrs)	Agency
Concrete gravity dam	Multiple monoliths	Vertical	0.1 – 0.5	USACE 1980
	Usually ≤ 0.5L	Vertical	0.1 – 0.3	FERC
	Usually ≤ 0.5L	Vertical	0.1 – 0.2	NWS
	Multiple monoliths	Vertical	0.1 – 0.5	USACE 2007

Dam breach Parameters

Accurately determining the breach location, size, and development time is vital for estimating the outflow hydrographs and downstream inundation in a dam breach scenario. Nevertheless, these parameters pose significant uncertainty and are among the most unpredictable aspects of the entire analysis. Several federal agencies have released guidelines that provide potential ranges of values for breach width, side slopes, and development time. The guidelines given by various agencies is shown in the Table 1.

Since Jamrani dam is a roller-compacted concrete gravity dam, the guidelines given by FERC were adopted and the following breach parameters as shown in Table 2 were inputted to model the breach.

Flow data and boundary condition

Boundary conditions are crucial inputs that have a significant impact on downstream floodwater in an analysis. It is important to carefully select appropriate boundary conditions that accurately represent the actual site conditions. In this analysis, the upstream boundary condition is represented by an inflow hydrograph, specifically the probable maximum flood (PMF) hydrograph provided by the dam authority as shown in Fig.4. The downstream boundary condition is set as normal depth, with a friction slope value of 0.0012. For the inline structure, the time series of gate opening serves as the boundary condition.

Flood mapping

Ras Mapper has been used for flood inundation at downstream of Jamrani Dam. Ras mapper in HEC-RAS shows the spatial extent of flood water with an underlayer of topographical or Google satellite map, which makes it easier for the user to identify the area coming under the extent of flooding.

RESULTS AND DISCUSSION

The study presents an analysis of the Jamrani dam failure caused by overtopping. Additionally, it includes a flood inundation map depicting the affected area spanning a 63 km stretch downstream of the reservoir.

Flood hydrograph and stage hydrograph

The unsteady flow simulation was conducted to analyze the effects of overtopping failures in the Jamrani dam. The simulation considered a downstream river stretch of 63 km. The HEC-RAS model was simulated from September 22, 2022, at

Table 2: Breach parameters

Parameter	Value
Final Bottom Width	80 m
Final Bottom Elevation	700 m
Left Side slope	0
Right side slope	0
Breach weir coef.	1.44
Breach formation time	0.1 (hrs)
Failure Mode	Overtopping
Trigger failure at water surface elevation	762 m

Table 3: Maximum discharge at profile lines

S. No.	Distance downstream (Km)	Maximum discharge (cumecs)	Time of arrival (hrs)
1.	20	105087.52	17:50 (Day 1)
2.	30	88274.41	19:30 (Day1)
3.	40	71896	21:20 (Day1)
4.	50	36379.43	23:00 (Day1)
5.	60	9134.04	01:00 (Day2)

12 am to September 24, 2022, at 02 am using the probable maximum flood (PMF) data and the obtained results corresponded to the same simulation period. The hydrograph depicted in Figure 5 illustrates the stage and flow characteristics at the dam cross-section resulting from a breach in the dam when the reservoir is at F.R.L. It provides a visual representation of how the flow and stage changes over time as the breach continues. At 16:00 hrs on 22/09/2022, the maximum flow rate through the breach at the dam cross-section is determined to be 46,473.64 cubic meters per second.

Flow variation at different profile lines

The profile lines drawn at every 10 km reach show the flood hydrograph for overtopping failure at F.R.L. Table 3 shows the maximum discharge and

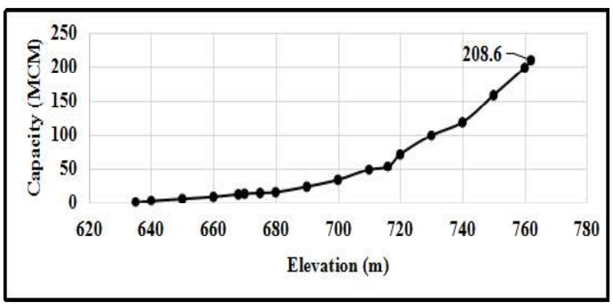

Fig. 3: Elevation-Capacity curve of reservoir

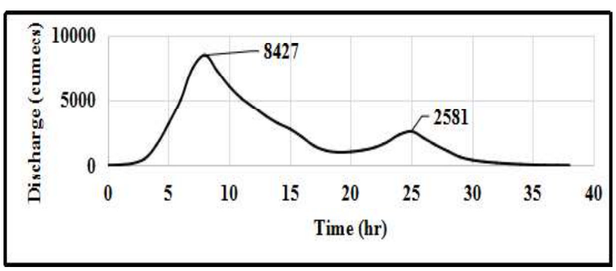

Fig. 4: Probable maximum flood

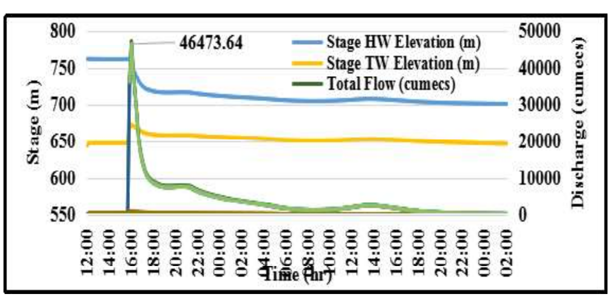

Fig. 5: Stage and flow hydrograph

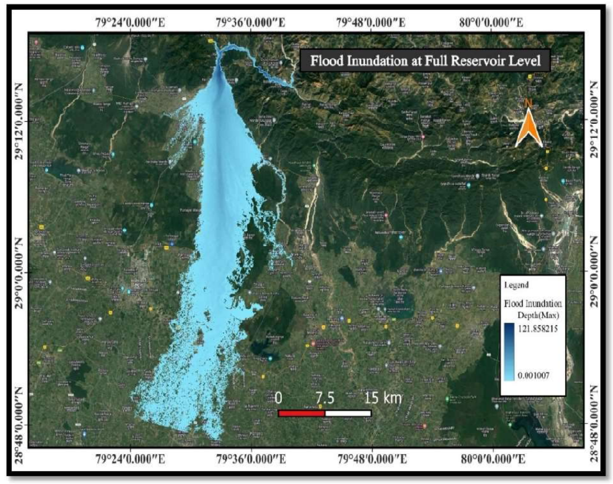

Fig. 6: Flood inundation map due to overtopping failure

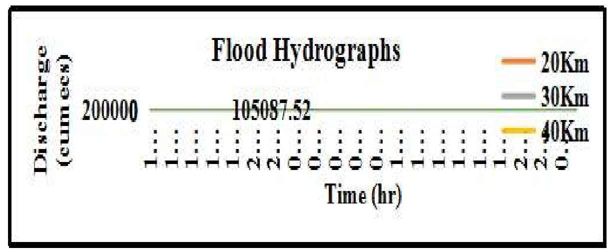

Fig. 7: Discharge at various profile lines

its time of arrival at every 10 km. It is evident that most areas downstream of the dam experience the highest flood discharge values on day 1 following the breach but the areas 60 kilometers downstream from the dam encounter the peak flood on day 2. The findings indicate that the peak flow magnitude is notably high in the immediate downstream area of the dam and gradually diminishes as it progresses further downstream. The maximum discharge at 20 km downstream is 105087.52 cumecs and at 60 km downstream is 9134.03 cumecs and the corresponding arrival time is 17:50 (Day 1) and 01:00 (Day 2) respectively. The results show a gradual decrease in peak flow after 20 km as the distance from the dam increases in the downstream region as shown in Fig. 7.

Flood inundation

HEC-RAS results are then opened in Ras mapper to generate floodplain maps. Fig. 5. Showcases the downstream areas affected by overtopping failure at full reservoir level. It was determined that a total area of 464.023 kmβ was inundated downstream due to overtopping failure. The maximum depth of flow observed was 121.964 m downstream of the dam.

CONCLUSION

A dam breach is an extremely catastrophic event, and the process of dam failure is highly complex and not yet fully comprehended. To gain insights into the dynamics of dam breaches, a study was conducted on the Jamrani dam in Uttarakhand, India, utilizing the HEC-RAS model for dam breach analysis. This model simulated the dam breach under unsteady flow conditions, considering overtopping failure mode at full reservoir level. The peak flow at dam cross-section is 46473.64 m^3/s. The maximum discharge of 105087.52m^3/s is obtained at 20 km downstream of the dam. The inundation area downstream of dam was measured to be 464.023 kmβ.Given the potential danger posed by dam failure to downstream communities and assets, the findings of this study provide valuable insights to implement preventive measures and safeguard lives and property from potential catastrophes in the inundated area. Furthermore, the study aids authorities in formulating an emergency response plan and devising effective flood mitigation strategies.

REFERENCES

Ackerman, C.T., Fleming, M.J., Brunner, G.W., (2008). Hydrologic and hydraulic models for performing dam break studies. In: Proceedings of the World Environmental and Water Resources Congress. 316: 1–11.

Central Water Commission. (2018). Guidelines for Mapping Flood Risk Associated with Dams, Ministry of Water Resources, Government of India, 285 p.

Chow, V.T. (1959). Open Channel Hydraulics. Mc Graw-Hill Book Co., New York, 19 p.

Federal Energy Regulatory Commission (1987). Engineering guidelines for the evaluation of hydropower projects, Office of Hydropower Licensing, Pp. 9-17.

George, A.C., Nair, B.T. (2015). Dam break analysis using BOSS DAMBRK. Aquat. Procedia 4,: 853–860.

https://bhuvanapp3.nrsc.gov.in/data/download/index.php BHUVAN India geo platform of India, 05/08/2023.

Hydrologic Engineering Centre. (2016). HEC-RAS River Analysis System, 2D Modelling User's Manual Version 5.0. U.S. Army Corps of Engineers, 25 p.

Ramola, M., Prasad, J. and Prasad Shiva H. J. (2019). Baur dam breach analysis using 2D HEC-RAS. J. Indian Water Resour. Soc, 39: 1-5.

Ramola, M., Prasad, J. and Prasad, H. J. Shiva. (2020). Baur dam breach analysis using various Manning's roughness values, P. J. R., 18: 286-289.

Ramola, M., Prasad, J. and Prasad, H. J. Shiva. (2021). Unsteady breach analysis using 2D HEC-RAS: A case study of Baur Dam, 'In: Sustainable Water Resources Development and Management (SWARDAM-2021)' at Aurangabad (GCE), during. March 8-9, Pp 230-235.

Singh, P., Prasad, J. and Prasad, H. J. Shiva. (2022). Sensitivity analysis of breach width parameter of Ramganga dam, using 2D HECRAS, P. J. R., 20: 335-340.

Wahl, T.L. (1997). Predicting embankment dam breach parameters-a needs assessment. In: Proceedings of the International Association for Hydraulic Research Congress (IAHR), pp. 48–53.

Xiong, Y. (2011). A dam break analysis using HEC-RAS. J. Water Resour. Prot.,03: 370–379.

Zhang, L. and Peng, M. and Chang, D.S. and Xu, Y. (2016). Dam Failure Mechanisms and Risk Assessment, John Wiley and Sons Singapore Pte. Ltd., Singapore, 67 p.

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