Breach Analysis of Earthen Dam

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***Abstract*—** Failure of a levee or dam breach can result in severe economic losses and loss of human life. To minimize these consequences, it's imperative to assess the risks associated with levee breaches. This involves accurately predicting the volume of water released during a breach and simulating the propagation of flood waves across the floodplain to create inundation maps. Despite extensive observation and research into representing dam breaches and deriving crucial breach parameters like width, height, and side slope, there is no universally accepted method for determining these parameters. This study aims to evaluate existing methodologies for dam breach analyses, highlighting their advantages, limitations, and the challenges that lie ahead in this field.

Earthen dams play a crucial role in water resource management and flood control. However, breaches in these structures pose significant risks to surrounding communities and infrastructure. This study explores the causes of earthen dam breaches, focusing on hydraulic, geotechnical, and structural factors. Through a comprehensive analysis of historical case studies and numerical modeling techniques, we elucidate the underlying mechanisms leading to dam failures. Furthermore, this research investigates effective mitigation strategies to enhance the resilience of earthen dams against breach incidents. By identifying key vulnerabilities and implementing targeted interventions, we aim to minimize the likelihood and impact of future breaches, ensuring the safety and sustainability of earthen dam infrastructure.

Keywords*— *Breach analysis; Geotechnical Engineering; Earthen dam and Gangapur Dam

1. Introduction

A dam is typically described as a structure erected across a river or stream, serving as a blockade. This impediment causes water to accumulate behind it, creating a reservoir. The side where water gathers is referred to as the upstream side, while the opposite side is termed the downstream side. The resulting body of water upstream is commonly known as a reservoir, dam reservoir, or storage reservoir. Water amassed in this reservoir can be utilized for agricultural irrigation via a network of canals or for drinking purposes. The resulting lake can serve recreational purposes. Additionally, the stored water's energy can be harnessed to power mills for grinding wheat or turbines for generating electricity. During floods, dams act as protective barriers for downstream towns and cities. Beyond these benefits, dams have various other uses including navigation, irrigation, and flood control. They also play strategic roles in warfare, aiding in the planning and control of enemy advancement. During the Second World War, the Dutch intentionally breached their dikes to impede the invading Germans.

[S.K. Garg] The development of civilizations worldwide is closely linked to the accessibility of water. Dams serve as human-made structures to harness water for various purposes such as irrigation, flood control, and hydro-power generation, playing a crucial role in human development. However, dams are not without drawbacks. They present significant hazards in the rare event of failure. Throughout the 20th century, there were approximately 200 notable instances of reservoir failures globally, resulting in the loss of over 8,000 lives.

Realizing the importance of dam safety, many countries in the world have initiated action to review the safety of dams in their countries and United States of America can be considered a pioneer in this field. The review conducted recently by US Army Crop of Engineers revealed that out of 8819 review inspection completed, 2925 dams were Support System for Water Infrastructural Security (DSSWISE) developed by the National Centre for Computational Hydro science and Engineering of the University of Mississippi, MIKE software by DHI, FLO-2D by FLO-2D Software Inc., SIMBA by ARS, and Win-DAM developed through a collaborative effort between ARS, NRCS, and Kansas State University.

Keeping in view the importance of the dam safety in our country, a dam safety organization was established in May 1979 in Central Water Commission to assist the state governments in various activities in dam safety. The dam safety organization also initiated action for reviewing the existing procedures of dam safety in the country and also evolves appropriate dam safety practices. [CWC- Dam Safety Organization]

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2. Problems in Dam Construction

Dams can cause problems too. Dams have drawbacks and disadvantages also. There are four major problems, in general, which are posed by huge construction. They are:

- Fish problem
- Submergence problem
- Failure problem

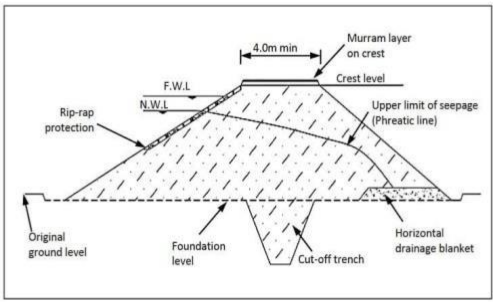


Figure Number. 1 Homogeneous Embankment Type

3. Modes of Failure of Earthen Dam

The various causes leading to the failure of earth dams can be grouped into the followingthree classes:

- Hydraulic Failure
- Seepage Failures
- Structural Failure.

Hydraulic Failure: Evaluate the maximum expected water level and flow rates, considering factors like rainfall intensity, upstream runoff, and reservoir capacity.

Seepage Failures: Conduct seepage analysis to determine potential seepage paths, evaluate the effectiveness of the drainage system.

Structural Failure: Excessive water pressure or loading beyond the design capacity can lead to structural failure. This could be caused by heavy rainfall, rapid snowmelt, or upstream development increasingrunoff.

Figure Number. 2 Breach Formation (Dam Failure)

4. Dam Breach Analysis – The Concept

The study of dam breaks relies on two main tasks: predicting the flood hydrograph resulting from a breach and simulating its downstream routing from the dam site. Essentially, the estimation of dam break floods involves these two primary components. Empirical methods employed to forecast breach parameters draw upon data gathered from past dam failures. Parameters related to dam breaches can be acquired through commonly employed empirical methods. These techniques rely on statistical analysis of data collected from documented dam failures, providing reasonably accurate predicted values when compared to observed values.

Dam breach inundation studies may be required for a host of purposes, including evaluation and establishment of the hazard potential class of a dam, estimation of the potential loss of life downstream of a dam and evaluation of dam safety risk and prioritization of dams within a group of dams being managed by an organization. In addition, it may be necessary for selection of the appropriate IDF for the dam and its spillway design, preparation of EAPs, preparation of inundation maps for implementing flood-warning systems as also for planning flood mitigation including emergency evacuation. Dam breach inundation maps may also find its use in risk communication, forinforming the public about the risk of living Downstream of dams. There are two primary approaches for dam breach analysis. These are the event-based approach and the risk-basedapproach. [CWS-Guidelines for mapping flood risks associated with dams]

5. The Modelling Software

For analyzing the dam breach process and routing the peak breach outflows to determine inundation depths downstream of the dam, a model DAMBRK was developed in 1977. It was followed by NWS Flood Wave Dynamic Model (FLDWAV), HEC-1, HEC- HMS, and HEC-RAS, amongst others. Some more developments include the NWS SMPDBK, Geo Dam BREACH developed by FEMA, Decision Support System for Water Infrastructural Security (DSSWISE) developed by the National Centre for Computational Hydro science and Engineering of the University of Mississippi, MIKE software by DHI, FLO-2D by FLO-2D Software Inc., SIMBA by ARS, and Win-DAM developed through aCollaborative effort between ARS, NRCS, and Kansas State University.

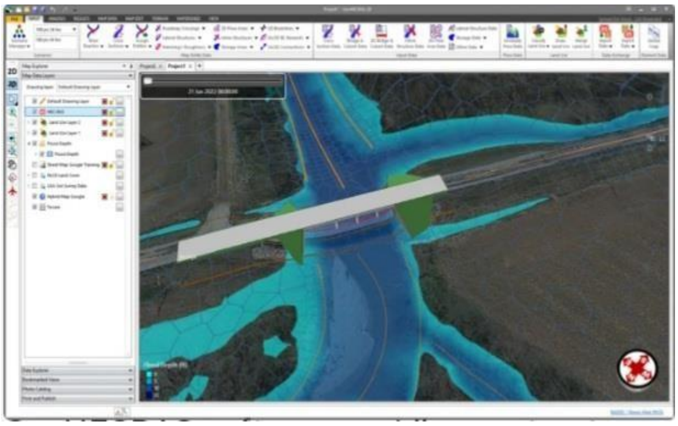


Figure Number. 3 (HEC-RAS)

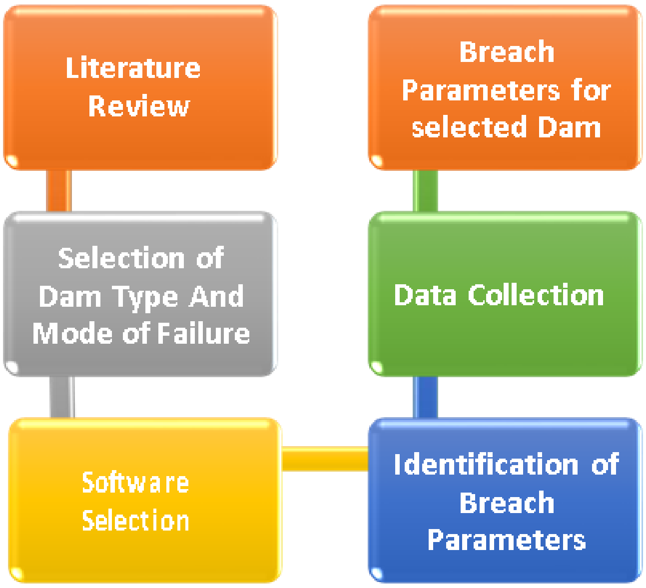
6. The HEC-RAS Software

HEC-RAS has been developed by the Hydrologic Engineering Centre of the US Army Corps of Engineers. The program has the ability to solve either the 2D full Saint Venant shallow water equations (with optional momentum additions for turbulence and Coriolis effects) or the 2D Diffusion Wave equations, as chosen by the user. The 2D nsteadyflowequations solver uses an Implicit Finite Volume algorithm, allowing for larger computational time steps with improved stability and robustness handling subcritical Flow.

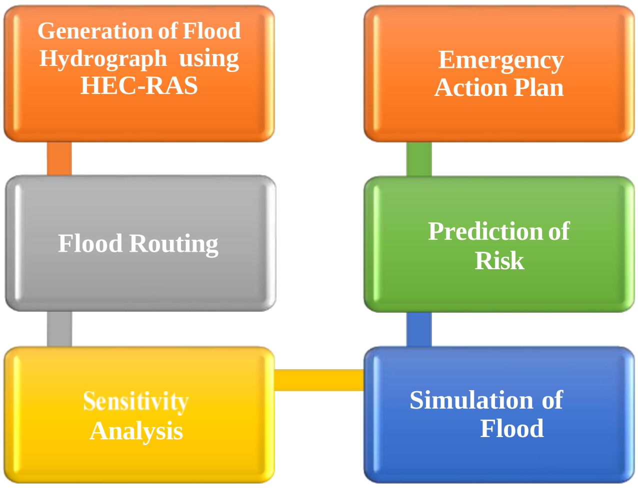
Regimes. The 1D and 2D solution algorithms are coupled through time steps. Each cell and cell face are defined as tables to have properties like elevation-volume, elevation- area, elevation wetted perimeter and roughness based on the resolution of the terrain model which is much smaller than the grid size of the mesh used for 2D computation. This allows much faster computation without losing details. It also hasdetailed flood mapping and flood animation capabilities.

7. Methodology

1) Literature Review
2) Selection of Dam Type
3) Mode of Failure
4) Selection of Software
5) Data Collection and Data Analysis



Flow Chart Number.1



Flow Char Number.2

8) Gangapur Dam

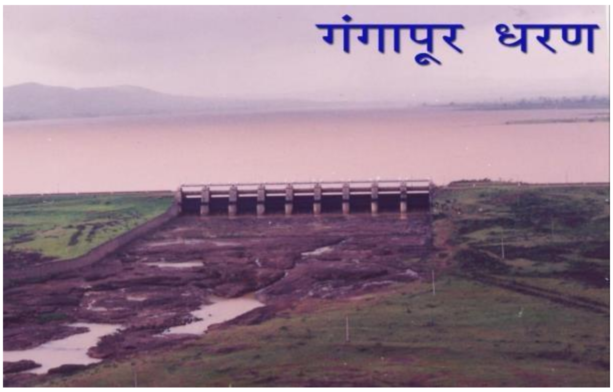


Figure Number.4 gangapur dam

9. *Calculations of Breach Parameters by Various Approaches*

Table 1. Calculations of Breach Width and Discharge by USBR

Sr.No.	hw	B=3hw	V=√(haxgx2)	A=Bxhw	Q=AxV	tf=0.011xB
1	5	15	9.904544412	75	742.8408	0.165
2	10	30	14.00714104	300	4202.142	0.33
3	15	45	17.15517415	675	11579.74	0.495
4	20	60	19.80908882	1200	23770.91	0.66
5	25	75	22.14723459	1875	41526.06	0.825
6	30	90	24.26107994	2700	65504.92	0.99
7	31	93	24.6621167	2883	71100.88	1.023
8	32	96	25.05673562	3072	76974.29	1.056
9	33	99	25.44523531	3267	83129.58	1.089
10	34	102	25.8278919	3468	89571.13	1.122
11	35	105	26.20496136	3675	96303.23	1.155
12	36	108	26.57668151	3888	103330.1	1.188
13	37	111	26.94327374	4107	110656	1.221
14	37.65	112.95	27.17890726	4252.568	115580.1	1.24245

Table 2. Calculations of Breach Width and Discharge by Von Thun and Gillete

Sr. No.	hw	Bavg	A=hwxBavg	V=√(2xgxhw)	tf =0.02hw+0.25	Q=AxV
1	5	67.4	337	9.90	0.35	3336.3
2	10	79.9	799	14	0.45	11186
3	15	92.4	1386	17.15	0.55	23769.9
4	20	104.9	2098	19.81	0.65	41561.18
5	25	117.4	2935	22.15	0.75	65010.25
6	30	129.9	3897	24.26	0.85	94541.22
7	31	132.4	4104.4	24.66	0.87	101214.50
8	32	134.9	4316.8	25.05	0.79	108135.84

9	33	137.4	4534.2	25.44	0.91	115350.048
10	34	139.9	4756.6	25.83	0.93	122862.978
11	35	142.4	4984	26.20	0.95	$130.58x10^3$
12	36	144.9	5216.4	26.57	0.97	$138.60x10^3$
13	37	147.4	5453.8	26.94	0.99	$146.92x10^3$
14	37.65	149.025	5610.79	27.18	1.003	$152.50x10^3$

Table 3. Calculations of Breach Width and Q is charge by Froehlich (2008) for OvertoppingFailure Mode

Sr. No.	hw	Bavg	A=hwxBavg	V=√(2xgxhw)	$tf=63.2\sqrt{(Vw/(gxhb^2))}$	Q=AxV
1	5	151.02	755.1	9.90	13.21	$7.47x10^3$
2	10	146.93	1469.3	14	6.06	$20.57x10^3$
3	15	140.18	2102.7	17.15	3.66	$36.06x10^3$
4	20	131.03	2620.6	19.81	2.42	$51.91x10^3$
5	25	118.30	2957.5	22.15	1.63	$65.51x10^3$
6	30	101.40	3042	24.26	1.05	$73.80x10^3$
7	31	97.29	3015.99	24.66	0.95	$74.37x10^3$
8	32	92.72	2967.04	25.05	0.85	$74.32x10^3$
9	33	87.57	2889.81	25.44	0.75	$73.52x10^3$
10	34	79.97	2718.98	25.83	0.63	$70.23x10^3$
11	35	72.50	2537.5	26.20	0.53	$66.48x10^3$
12	36	62.80	2260.8	26.57	0.41	$60.07x10^3$
13	37	42.11	1558.07	26.94	0.21	$41.97x10^3$
14	37.65	0	0	27.18	0	0

Table 4. Calculations of Breach Width and Discharge by Froehlich (2008) for Piping Failuremode

Sr. No.	hw	Bavg	A=hwxBavg	V=√(2xgxhw)	$tf=63.2\sqrt{(Vw/(gxhb^2))}$	Q=AxV
1	5	116.17	580.85	9.90	13.21	$5.75x10^3$
2	10	113.03	1130.3	14	6.06	$15.82x10^3$
3	15	107.83	1617.45	17.15	3.66	$27.74x10^3$

4	20	100.79	2015.8	19.81	2.42	$39.93x10^3$
5	25	91	2275	22.15	1.63	$50.39x10^3$
6	30	78	2340	24.26	1.05	$56.77x10^3$
7	31	74.83	2319.73	24.66	0.95	$57.20x10^3$
8	32	71.32	2282.24	25.05	0.85	$57.17x10^3$
9	33	67.36	2222.88	25.44	0.75	$56.55x10^3$
10	34	61.51	2091.34	25.83	0.63	$54.02x10^3$
11	35	57.77	1951.95	26.20	0.53	$51.14x10^3$
12	36	48.31	1739.16	26.57	0.41	$46.21x10^3$
13	37	32.39	1198.43	26.94	0.21	$32.28x10^3$
14	37.65	0	0	27.18	0	0

10. Conclusion

1. Identification of the primary cause(s) of the breach, such as hydraulic overload, structural deficiencies, or geological factors.

2. Assessment of the extent and severity of the breach, including the volume of water released, affected areas, and potential downstream impacts.

3. Evaluation of the effectiveness of existing dam safety measures and emergency response protocols.

4. Recommendations for improvements in dam design, maintenance practices, monitoring systems, and emergency preparedness to enhance overall dam safety.

5. Consideration of the environmental, social, and economic consequences of a dam breach and strategies for minimizing risks and mitigating impacts in the future.

6. Implications for regulatory policies and guidelines governing earthen dam construction, operation, and inspection.

7. Earthen dams are susceptible to breaches due to various factors such as poor construction, inadequate maintenance, extreme weather events, or geological conditions

8. After conducting a thorough breach analysis of the earthen dam, it is evident that the breach was primarily caused by a combination of factors including inadequate maintenance practices, heavy rainfall exceeding design capacity, and underlying geological conditions. Maintenance protocols, enhance monitoring systems, and consider necessary design

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