Dam Break Analysis of Idukki Dam using HEC RAS

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Abstract - *Idukki reservoir, with an active capacity of 1459000000 m3 is a part of the Idukki Hydroelectric Project and comprises of Idukki Arch Dam, Kulamavu Dam and Cheruthoni dam. During the monsoon period when the dams are full at its Maximum Reservoir Level (MRL) or in an adverse event of dam break, the maximum discharge gets released from these dams. This results into floods on downstream and may cause disaster in cities or towns settled on the banks of the reservoir. This paper presents a case study of dam break analysis of Idukki Arch Dam using HEC-RAS software which involves prediction of dam break parameters, flood hydrograph, time of arrival of flood wave, peak flow. The resulting flood wave is routed along downstream using unsteady flow equations. In order to correctly draw the flood risk maps, the HEC-RAS method has been used together with the HEC-GeoRAS extension as an extension to the ongoing study.*

Key Words: *Idukki dam, Dam break analysis, Flood modelling, HEC-RAS*

1. INTRODUCTION

Dam is a barrier that impounds water that plays a vital role in the economy of the country. The water retained is generally used for irrigation, aquaculture, industrial use, human consumption, etc. However, in the unlikely and rare event of their failure, these may cause catastrophic flooding in the downstream area which may result in huge loss and damage to human life and property. In this study the dam break analysis and flood modelling of Idukki reservoir is done with the help of HEC-RAS. Hydrologic Engineering Center's River Analysis System (HEC-RAS) modelling software developed by the U.S. Army Corps of Engineers, a standard for dam-breach flood-inundation models, is used to perform steady-flow simulations to model the dynamic nature of the flood wave produced by a dam-breach scenario. The reservoir consists of three dams. They are Idukki dam, Cheruthoni dam and Kulamavu dam.

2. SCOPE AND OBJECTIVE

The prediction of the dam break flood is very important for the purposes of planning and decision making concerning to dam safety, controlling downstream developments, contingency evacuation planning and real time flood forecasting. For assessing the flood damage due to dam breach it is necessary to predict not only the possibility and mode of a dam failure, but also the flood hydrograph of discharge from the dam breach and the propagation of the flood waves. The studies are to map or delineate areas of potential flood inundation resulting from a dam breach, flood depth, flow velocity and travel time of the flood waves etc. Knowledge of the flood wave and flood-inundation area caused by a dam breach can potentially mitigate loss of life and property damage. The significance of the study is to develop the river hydraulics model, simulate a dam failure and map the resulting flood wave. The proper modelling of the hazards associated with dam break will assist in land use planning and developing emergency response plan to help mitigate catastrophic loss to human life and property that might be inflicted by floods.

Following are the objectives of the study

- To conduct dam breach analysis of Idukki Arch Dam using HEC-RAS 5.0

Dam-breach flood-inundation maps indicate areas that would be flooded as a result of a dam failure. The inundated areas depicted on flood-inundation maps are approximate, and accuracy of such maps is a function of the accuracy of the topographic data, the hydraulic models on which the maps are based, the assumptions made about the dam failure mode, and the initial flood wave.

3. METHODOLOGY

Dam break analysis can be done using the flood routing techniques proposed by St. Venant's equations for unsteady flow. His approach solves both the continuity and momentum equations for a differential volume of one-dimensional flow, where the forces on the control volume are limited to the effect of gravity, pressure variation, and friction or roughness of the channel walls.

Mass is conserved in the solution and the effect of acceleration within the control volume and momentum fluxacross the upstream and downstream faces are considered. It consists of two independent variables Q and t. Solution of this equation depends on the number of cross-sections. Because of the complexity in solving the entire equation simultaneously software HEC-RAS has been selected. The methodology adopted in this research is that the salient features and breach parameters that are collected from after the site visit is provided as input to the software where we obtain the flood hydrograph as the output for dam break analysis. HEC-RAS is Hydrologic Engineering Center's River Analysis System software. It is developed by U.S Army Corps of Engineers. This software allows to perform one dimensional steady flow, unsteady flow calculations, sediment transport computations and water quality analysis. One dimensional approach to flood inundation modeling only considers one dimension of the flood flows in the direction of x axis(downstream direction). It is best represented by St. Venant's formula used for calculating the one dimensional flow of the flood wave. The lateral and longitudinal geometry of the stream determines how peak of the flood wave s reduced as it moves downstream, the travel time of the peak flood between points of interest, maximum water stage at point of interest and change in shape of hydrograph as it moves downstream. These effects are governed by factors such as bed slope, cross sectional area and geography of the main channel.

In order to do the dam break analysis and flood modelling the salient features regarding the reservoir, the dams that have to be analyzed etc. are to be collected. To analyze the dam for dam break analysis we require data like breach data flow data, Manning's n etc. The input for flood modelling are input for flood modelling storage area data, inline structure data, geometric data, entering flow data and the boundary conditions.

4. STUDY AREA

4.1 Idukki Reservoir

Idukki reservoir consist of three dams. They are Idukki dam, Kulamavu dam, and Cheruthoni dam. The water impounded by these three dams of Idukki, Cheruthoni & Kulamavu has formed a single reservoir spread over 60 km on a height of 2300 ft above Mean Sea Level.The Idukki Dam is a double curvature arch dam constructed across Periyar River in a narrow gorge between two granite hills. Cheruthoni Dam is located 1 km west of Idukki dam. The spill way of the Idukki Reservoir is in the Cheruthony dam. Kulamavu Dam was constructed to prevent the water escape through a rivulet called Kalivally, 30 km west to Idukki Arch Dam. It is a 100 metres tall Masonry gravity dam. Construction of this Cheruthoni Dam, Idukki Arch Dam and Kulamavu Dam created an artificial lake of 60 km2 and the water stored, is used for production of electricity at the Moolamattom Power house. The power house at Moolamattom is the biggest underground power station in India and the pressure shaft is the largest in the country. Cheruthony is the largest and highest gravity dam in Kerala. Storage of water in Idukki Reservoir started in February, 1973. Moolamattom Power Station was commissioned in February 1976 by Prime Minister Indira Gandhi.

4.2 Idukki Dam

The Idukki Dam is a double curvature arch dam constructed across the Periyar River in a narrow gorge between two granite hills Kuravan and Kuravathi in Kerala, India. At 167.68 meters, it is one of the highest arch dams in Asia. It was constructed and is owned by the Kerala State Electricity Board. It supports a 780 MW hydroelectric power station in Moolamattom, which started generating power on 4 October 1975. Technically, the dam type is a concrete, double curvature parabolic, thin arc dam. This dam was constructed along with two other dams at Cheruthoni and Kulamavu. Together, the three dams have created an artificial lake that is 60 km^2 in area. The stored water is used to produce electricity at the Moolamattom Power house, which is located inside nearby rocky caves. The Government of Canada aided in the building of the dam with long term loans and grants.

Table -1: Salient features of Idukki Arch Dam

Location	Idukki,kerala, India
Type	Concrete double curvature,Parabolic thin arch
Impounds	Periyar River
Height	169.91m(554ft)
Length	365.85m1200ft)
Width at the top	7.32m
Dam Volume	450000cu.m
Spillways	Nil
No.of cross sections	7
Dam crest length	513.0

5. DAM BREAK ANALYSIS

5.1 Input Parameters

The following data are required for a typical dam break analysis:

- Salient features of dam in study reach of the river.
- Design flood hydrograph.
- Cross-sections of the river from dam site to the most downstream location of interest.
- Elevation - storage/area relationship of the reservoir.
- Manning's roughness coefficient for different reaches of the river under study.
- Breach Geometry.
- Time taken for Breach formation.
- Reservoir elevation at start of failure and initial water elevation

The flood hydrograph obtained by giving these salient features in the software is used as the input for flood modelling in HEC GEO RAS

5.1.1 Breach Data and Cross Sectional Details

The breach parameters are time of breach formation, final bottom breach width, side slope of breach, final elevation of breach bottom, initial elevation of water level in the reservoir, elevation of water when breach begins to form and elevation of top of dam. The cross sectional deatails regarding the profile is also provided.

5.1.2 Flow Data

Boundary conditions are required in order to perform the calculations. In a subcritical flow analysis, boundary conditions are required only at the downstream end of river system. In a supercritical flow analysis, boundary conditions are required only at the upstream end of river system and in a mixed flow regime boundary conditions are provided at the open ends of the river system.

5.1.3 Dam Breach Parameters

The shape of the peak breach outflow hydrograph is influenced by the storage in the impoundment at the time of breach, reservoir inflow at the time of breach, size of the dam, and most importantly, the dam type's erodibility and mode of assumed failure. For instance, a brittle concrete or structural failure will have a much faster time of breach development as compared to an overtopping failure of a large, cohesive, well compacted, and well vegetated embankment. Since the outflow hydrograph can vary widely depending upon these factors, careful consideration of the dam breach parameters is needed.

5.1.4 Reservoir Data

To predict the flood hydrograph from the reservoir, it is necessary to have elevation- storage relationship for the reservoir.

5.1.5 Catchment Hydrology

Inflow into the reservoir, reservoir condition at the time of failure and base flow conditions in the river valley downstream may combine to have a significant effect on the predicted flood conditions, depending on the size and nature of the reservoir and dam

5.1.6 Topographic Data

Topographic data representing the whole area potentially liable to flooding is required. The extent of this data should not be underestimated. Floods resulting from dam failure can be significantly larger than natural floods. Required topographic data will therefore extend widely across floodplains and up-valley slopes well above normal flood levels. Details of major structures that may form an obstruction to flow are also required, such as road and railway embankments and bridges and-major river control structures.

The accuracy of a dam break study is different from that of a river modelling study. Traditional river modelling simulates natural floods that occur within defined floodplain areas. Our knowledge of typical flow conditions and modelling parameters such as channel and floodplain roughness for these events is relatively good. For a dam break model the flow conditions typically exceed natural events by a large margin meaning that there is little calibration data and the flooded terrain is outside of the normal floodplain areas making the estimation of channel roughness difficult.

5.1.7 Boundary Conditions

In this analysis, upstream boundary condition provided is flow hydrograph and downstream boundary condition is normal depth. This option uses Manning's equation to estimate a stage for each computed flow. To use this method, the user is required to enter a friction slope for the reach in the vicinity of the boundary condition. Rating curve is the other option which is used as downstream boundary condition. Lateral inflow hydrograph is used as internal boundary condition. This option allows the user to bring in flow at a specific point along the stream.

5.2 Results

The graphics include X- Y plots of the river system, schematic cross sections, profiles, rating curves, hydrographs, and many other hydraulic variables. The standard output table consists of river station, total, minimum channel elevation, maximum water surface elevation, critical water surface elevation, energy gradient slope, top width, Froude number and velocity of channel. User can create table with additional variables.

5.3 Analysis of Idukki arch dam

5.3.1 Input for Idukki Arch Dam

1) Manning's 'n'= 0.04

2) Left of bank = 654m

3) Right of bank = 655m

4)Expansion and contraction coefficient = 0.1 and 0.3 respectively

Table -1: Cross Sectional Details

Reach	Station	Elevation
Reach 1	0	654
	75	640
	150	623
	225	612
	300	606
	375	604
	455	605
	525	612
	600	629
	685	655

5.3.2 Output of Analysis

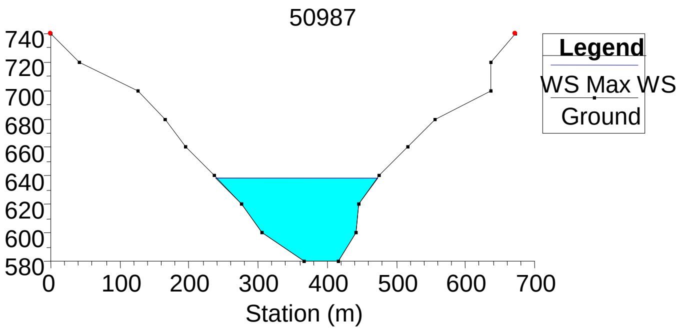


Fig -1: Cross section at 5023m away from Dam

River valley of 51km was considered for the analysis from Idukki dam to Thattekkad. Cross sections were taken at closer intervals.

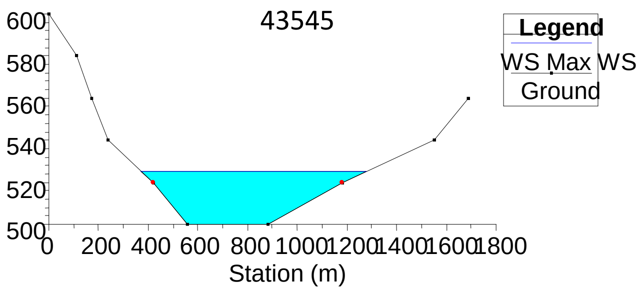
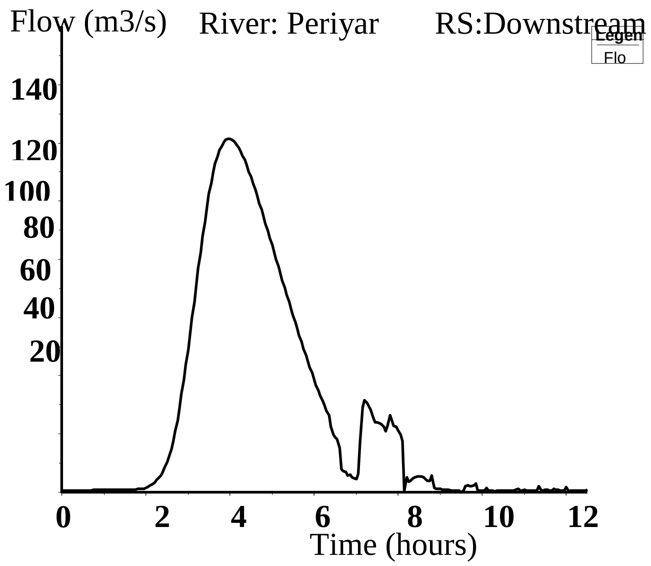


Fig -1: Cross section at 7442m away from Dam

5.3.3 Flood Hydrograph

Maximum flow occurs at downstream after 4 hours of break formation. Then the flow decreases with increase of time.



5.3.4 Output Table

Table shows maximum water surface elevation at different locations of downstream of the dam. Column1 shows the sections at which cross section of valley changes abruptly. Column 5 shows the time of arrival of maximum flow in the given sections. Velocity of flow depends on flow area. The maximum flood was found to be 12080.46 cumec which was at end of the valley.

River Sta	Q Total	Min Ch El	W.S. Elev	Crit W.S.	Vel Chnl	Froude no. Chl
	(m3/s)	(m)	(m)	(m)	(m/s)	
51000	9906	580	640.34		0.52	0.23
50999	9078.24	580	640.34	586.6	0.52	0.23
50998	Inl Struct					
50987	8027.29	580	638.24		9.35	0.05
50800	7406.1	580	638.28		9.23	0.02
50500	5594.72	580	638.29		9.12	0.01
50212	3645.42	580	638.28		9.0	0.01
49862	1835.07	580	638.27		8.88	0.23
49422	1312.72	580	621.18		8.72	0.54
48712	1438.77	580	608.06		8.56	0.01

48429	5205.44	580	608.37		8.43	0.02
47749	7309.24	580	611.06		7.96	0.03
46955	1695.95	580	603.23		7.80	0.01
46515	2042.38	580	597.03		7.62	0.01
45997	3004.51	540	567.29		7.40	0.07
45655	6874.11	540	554.74		7.02	0.09
45246	1211.33	520	541.38		6.76	0.3
44295	8773.1	500	522.79		5.97	0.1
43885	920.96	500	514.06		5.85	0.01
43545	7197.59	500	525.32		5.45	0.03
42981	412.41	440	478.84		5.32	0.22
41691	10345.44	380	393.37		4.87	0.09
41001	1271.86	360	363.84		4.67	0.03
40301	822.52	340	354.97		4.67	0.13
39801	1108.17	340	348.13		4.65	0.01
39300	928.72	320	332.61		4.63	0.11
38800	775.3	320	326.47		4.62	0.01
37720	998.17	300	306.31		4.60	0.01
37220	1124.71	260	266.95		4.57	0.01
36220	1407.11	260	266.65		4.54	0.06
35620	936.38	260	269.17		4.53	0.07
34810	2598.71	260	266.14		4.49	0.62
33290	8084.51	240	261.55		4.46	0.63
32820	2175.94	220	231.91		4.42	0.09
31520	6840.37	220	229.82		4.40	0.08
30680	5908.55	200	245.07		4.34	0.07
30360	1413.07	200	222.47		4.18	0.01
29700	4210.38	200	214.11		4.09	0.46
28850	1781.26	200	207.04		4.0	0.09

28550	1133.52	200	209.12		3.94	0.13
27650	1311.21	200	203.95		3.84	0.07
26950	996.95	160	166.74		3.72	0.05
26150	1010.13	140	159.38		3.61	0.02
25550	1299.58	140	159.43		3.43	0.01
24550	1139.85	120	159.47		2.91	0.11
22750	5174.1	120	141.28		2.83	0.11
21750	3979.51	100	127.62		2.65	0.12
20250	4753.11	60	75.31		2.42	0.23
19250	4823.89	55	74.55		2.32	0.11
17450	15368.4	55	75.18		2.28	0.11
16950	12197.8	55	74.66		2.22	0.12
15150	4174.52	55	74.04		2.15	0.03
13650	4063.64	55	73.96		2.09	0.02
12750	3896.33	55	73.94		1.99	0.02
11370	3615.23	55	73.92		1.92	0.02
10720	3480	55	73.91		1.84	0.01
9830	3303.67	55	73.86		1.78	0.05
8180	1957.88	55	73.86		1.74	0.01
7380	1901.37	55	73.88		1.70	0.02
6110	1651.85	55	73.91		1.62	0.01
5650	1122.97	55	73.91		1.57	0.01
4130	1097.91	55	73.92		1.55	0.01
2630	1860.64	55	61.79		1.44	0.03
1130	12256.9	35	54.35		1.37	0.05
730	12082.8	35	54.3		1.32	0.07
0	12080.5	35	53.21	45	1.27	0.28

6. CONCLUSION

Overtopping mode of failure of the structure was considered for the analysis. The parameters of breach selected is reasonable for the dam break flood generation. The peak flow at downstream of river reach is 28345.8 cumecs for Idukki dam. The depth of flow at different location vary from 58.24m (just below Idukki dam site) to18.21m at the end of the reach. Manning's roughness coefficient (N) was found to be most influencing point in the analysis.

The details of water surface elevations, time of arrival of maximum flow at different locations of the valley gives an idea about extent of flooding

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