IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 17, Issue 2 Ser. I (Mar - Apr 2020), PP 43-52
www.iosrjournals.org

Dam Break Analysis of JAWAI Dam PALI, Rajasthan Using HEC-RAS

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Abstract: *Due to old methods of construction dam was under designed and with use of poor materials of construction it is prone to collapse due to aging. Moreover the magnitude of peak floods to be used for the spillway design was based upon rough estimates which do not according to the modern estimates of extreme floods as suggested by experts of the International committee on large dams and the seismic potential was also under- estimated thus there are more chances for the dam to failure and such an accident will result in economic loss of states which mainly depends on river water. So keeping these points in mind an analysis of Jawai dam failure which is situated in Sumerpur town of Pali district Rajasthan and built in 1957 by Raja Umaid Singh has been done with the help of HEC-RAS to get the breach characteristics of dam and with the help of Arc-GIS and HEC-GeoRAS inundation mapping is made of downstream area of dam so that proper hazard prevention and mitigation measures can be taken at the time of such an accident and economic losses can be reduced.And results shown by HEC-RAS describe that for PMF 7267.34* m^3/s*, maximum stage will be 243.89 meter upto 7 km downstream and from there it reduces to 133.38 meter and it ahead it little varies .from the above results it is proved that flow area is different for different cross section, near the dam flow area is 101697 to approximately 12000 square meter and from 7 km downstream it suddenly reduces to 25929.12 to approximately 15000 square meter area. And full breach formation occurs within 12 to 13 hour for assumption taken in 1 hour interval hydrograph for boundary condition in unsteady flow analysis.*

Date of Submission: 01-03-2020 Date of Acceptance: 16-03-2020

I. Introduction

The kinds of dams that are mainly built are given below

- Gravity dam
- Arch dam and multi arch dam
- Embankment dam
- Steel dam, and timber dam
- Buttress dam

There are a lot of mechanisms that can be the prime cause of a dam failure. The following are kind of mechanism that can cause dam failure:

- Earthquake (internal and underneath the dam)
- Upstream failure of dam
- Overtopping failure of dam
- Equipment failure/malfunction (gates, etc.)
- Landslide of dam
- Piping failure of dam

Wurbs (1988) studied the available model as simplified dam break flood forecasting model SMPDBK, national weather service (NWS), Dam break flood forecasting model, simplified dam SMPDBK and compared and suggested the use of DAMBRK or SMPDBK, based on the extent of precision required resources and input data existing. Reclamation (1988) in his study suggested Parametric Dam Breach Models, Physical Dam Breach Methods, Predictor Equations for Dam Breach methods of analysis of dam failure. Singh and Snorrason (1984) used HEC-1 and DAMBRK models to check the variation in peak outflow by changing breach parameters. They changed breach width, depth, and failure time of 20 actual dam data to check the variation in peak outflow but their results showed that for huge storage peak of outflow did not changed so much by changing failure time its change was only 1 to 5% but as they changed breach width big changes as 35 to 87% were found in peak outflow and less changes were found only 6 to 50% in small reservoirs.

The loss of life from dam failure can be mostly affected by Warning time and migration time. Warning time is the total of breach initiation (given below), and breach formation time, and flood wave travel time from the place of dam to population center place. When placing hazard classification good prediction of warning time is essential. Bureau of reclamation has developed Case history based procedures which indicate that the loss of life vary from .03% of the population at danger when the warning time is 89 minutes to 53% of the population at danger when the warning time is less than 14 minutes (Brown and Graham, 1988). Extra modern work by Decay and McClelland (1991) predict same results to warning time. Costa (1985) told that most probably the average number of fatalities per dam failure is 20 times greater when there is scarce or no forewarning.

Until the 1990s National Weather Service DAMBRK or FLDWAV model, the NWS Simplified Dam-Break Flood Forecasting Model (SMPDBK), the HEC-RAS model from the U.S. Army Corps of Engineers were most commonly flood routing models or one of numerous commercial models with similar capabilities. Since the 1970s three major theories for dam-break flood modeling had risen. First theory was to get the breach outflow hydrograph directly and then using any existing model flooding consequences in downstream could be determined. In second theory breach was parameterize for describing its growth with time in relatively mathematical terms, and by combining the description of the breach growth with a weir equation or other proper model for simulating the hydraulic presentation of breach opening the breach outflow hydrograph was determined. The third theory is to use a combined model that simulates definite erosion processes and the associated hydraulics of flow through the developing breach to yield a breach outflow hydrograph.

Wahl (1998) used ten references for providing twelve formulas, developed by regression analysis of case study data from valid dam failures to directly calculate the peak outflow discharge as a function of dam. . SCS (1981) and Froehlich (1995) gave the most widely used predicting peak flow equations. An analysis by Wahl (2004) found in his study that equation given by Froehlich (1995) had lowest uncertainty of the peak flow prediction Advantages of this theory were its simplicity and quickness.

II. Study Area

My study Area is JawaiDam.This dam has been built nearby Sumerpur in the Pali district and its coordinates are 25.070707 degree N and 73.156586 degree E on Jawai River. It is largest dam in western Rajasthan. Jawai River originates from Udaipur and moves towards Jalore and Pali districts where it meets with many tributaries during its path of flow. The course of this river with its movement from one part of Rajasthan state to another is worth noticeable. Main tributaries of this river are Surkhi River. Another tributary which submerges with this river is Khari River.

Table 3(a): (Jawai Dam characteristic)

1.	Catchment area(Sq. miles)	304
2.	Average rainfall (Inches)	32Inches
3.	Dam work started in	May1946
4.	Dam work completed	Year 1957
5.	Irrigation First started	1951 of Rabi
6.	Main dam is lime masonry gravity dam(Feet)	3030
7.	Height of dam above deepest foundation(Feet)	166
8.	Ogee types Spillway(Feet)	13 Gates with 50×15
9.	Lowest R.L.(Metre)	913.00
10.	Non overflow Top R.L.(Metre)	1032.00
11.	Parapet top R.L.(Metre)	1035.00
12.	Flood discharge capacity (Cusec.)	150,000.00 Cusecs
13.	Dead storage (Mcft.)	494.50 Mcft.
14.	Sluice sill R.L.(Feet)	967.00
15.	Overflow crest width(Feet)	24.00
16.	Base width of masonry at overflow(Feet)	88.00
17.	Clear water way(Feet)	650
18.	One inspection gallery(Feet)	12.5
19.	North saddle dam length(Feet)	700
20.	South saddle dam length(Feet)	300

III. Methodology

4.1 Introduction

dam break analysis of Jawai dam has been done by collecting data from site of Jawai dam and W.R.D. of SumerpurRajsthan. Made it geo referenced in Arc-GIS and create a file in form of Jawai.

4.3 HEC-GeoRAS

Geometric data and steady flow data are the main inputs to HEC-RAS model and the output is the water level for each cross section. A Digital Terrain Model (DTM) of 30 m x 30 m resolution using 3D spatial analysis tool bar in ArcGIS software in the form of Triangulated Irregular Network (TIN). TIN was used for extracting the station-elevation data along the cross sections and reservoirs. It was also helpful in visualizing the terrain. The elevation data extracted from the terrain was used to locate the flood plain. HEC-GeoRAS preprocessing involved creation of many RAS themes like bank line, flow path centre line, stream centre line, cross sectional cutline's, land use area, storage area in GIS format.

4.4Analysis Process for HEC-GeoRAS
It usually contains these steps:
- Data pre- processing
- Model execution
- Post-processing/ result visualization

4.5 Constructing RAS Themes
In HEC-GeoRAS, each attribute in form of cross section, river banks, and hydraulic structures is saved in a different feature class called as RAS layer. And it helps in making geometric file for HEC-RAS. So before creating Jawai River attributes in GIS, first create empty GIS layers using the RAS Geometry menu on the HEC-GeoRAS toolbar. In this Jawai dam break analysis we have created layers for river, flow paths, stream line, inline structures, banks, lateral structural, Xs cut lines, storage area.

4.6 Export HEC-GeoRAS Data to HEC-RAS
Now open the HEC-RAS software to import geometric file from HEC-GeoRAS and to give all unsteady flow inputs in that. For this open a new project and save it and then import geometry data in HEC-RAS.

4.7 Working of HEC-RAS Software
For steady and unsteady flows its working based on one dimensional energy equation. In this energy losses are evaluated by friction and contraction/expansion. For unsteady flow it solves 1D saint venant equation using an implicit, finite difference method and momentum equation which ultimately depends upon dynamic wave routing or hydraulic routing.

4.8 Entering Jawai dam breach characterstics
Following Data needed to execute a dam breach analysis:

4.8.1 Inline Structure of Jawai dam
This point is for the specific inline structure (Jawai dam) on which we perform a breach analysis**.**

4.8.2 Breach This Structure
This point is for turning the breaching option on and off without getting rid of the breach data. This is a check for the software to actually perform the dam breach

4.8.3 Centre Station
This point is for entering the cross sectioning (Jawai dam) of the centerline (440.21) of the breach. The stationing is based on the inline structure.

4.8.4 Final Bottom Width
This is bottom width of the breach when it has reached its maximum size as in our case it is 122.22 meter.

4.8.5 Final Bottom Elevation
This is the bottom elevation of the breach when it has reached its maximum size as in our case it is 89.67.

4.8.6 Left Side Slope
This option is for entering the left side slope for the trapezoid that will signify the final breach shape. If zero is given for both side slopes, the breach will then be rectangular.

4.8.7 Right Side Slope
This is for entering right side slope for the trapezoid that will represent the final shape.

4.8.8 Full Formation Time (hrs.)
It represent the time from the intitation of the breach until the breach has reached the full size.

4.8.9 Failure Mode
Failure mode of the breach can be done by two ways in HEC-RAS. One is overtopping failure and second is piping failure. Overtopping failure mode is used when the water surface overtops the entire dam and erodes its way through the embankment. Piping failure mode should be used when the dam fails due to seepage through the dam, which causes erosion. Which is turn causes more flow to go through the dam, which causes even more erosion. As in our study we have taken overtopping failure.

4.8.10 Starting WS
This point is only used if we have selected a trigger failure mode of water surface elevation. We give a water surface elevation into this option. It is elevation of water surface at which the breach will begin to occur, once the water behind the dam has reached that elevation.

IV. Results

Results of dam break analysis of Jawai Dam are given below.

5.1 Stage and Flow Hydrograph for River Station 12000

As shown in Figure (5.1) stage will maximum at 1April 2015 at 13.00 as we have taken 24 hrs Flood time at which full dam breach formation will take place and at the same time outflow from spillways will maximum. That is 7300.20 and occurs at 13.00.

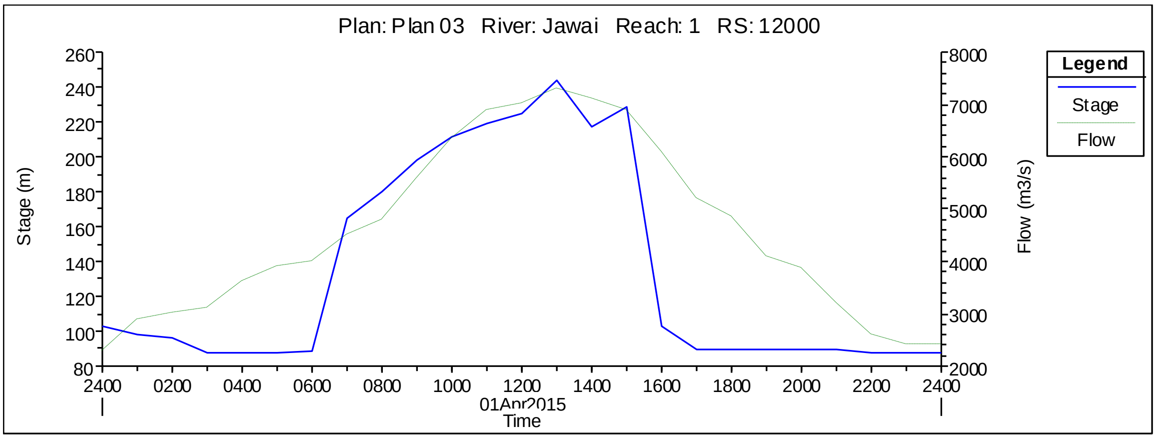

Figure 5.1 Stage and flow hydrographs for river station 12000

5.2 Hydraulic Property for River Station 12000

Hydraulic property for the same river station (12000) is given in Figure (5.2) and remaining all details is given in Table 5(a).From the Figure (5.2) it can be said that as elevation of water surface increases flow area, conveyance and storage area also increases.

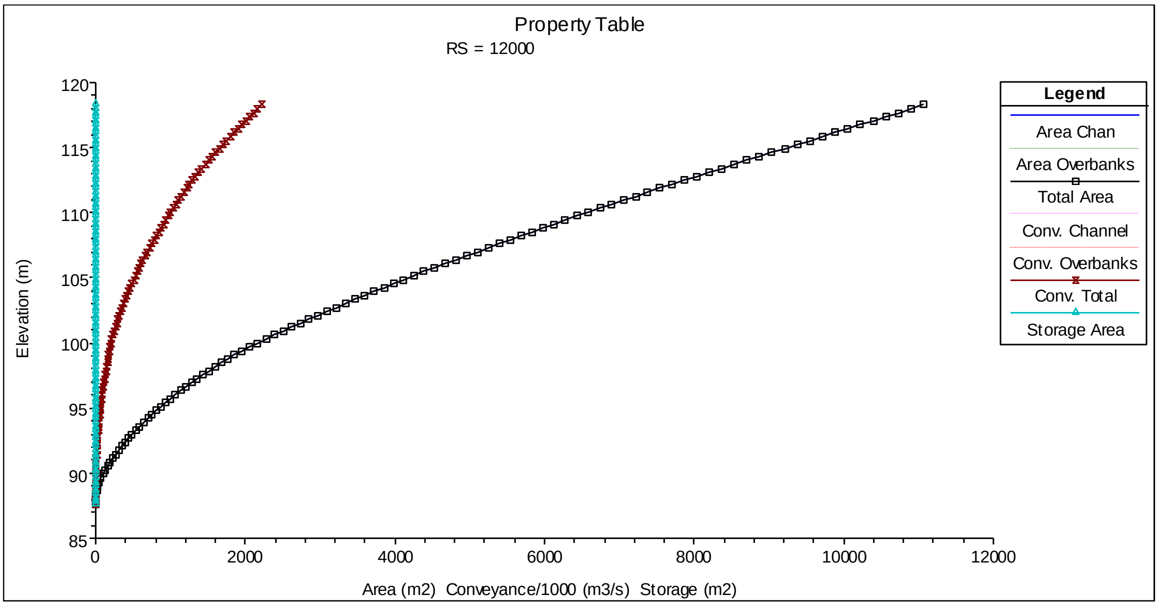

Figure 5.2: Hydraulic property of river section 12000

Table 5 (a): Hydraulic output for river station 12000 for maximum water surface

Enegy grad. Elevation (m)	243.84	Element	Left OB	Channel	Right OB
Velocity head (m)	0	Manning constant		0.035	
Water surface Elevation (m)	243.84	Length of reach (m)	121.92	121.92	121.92
Crit Water surface (m)		Area of flow (m2)		101697.6	
Energy Grad. Slope (m/m)	0	Area (m2)		101697.6	

Total dischg. (m3/s)	7300.2	Flow (m3/s)		7300.2	
Top Wid. (m)	762	Top Wid. (m)		762	
total velocity (m/s)	0.07	Avgerage Velocity (m/s)		0.07	
Maximum channel Dpth (m)	156.2	Hydraulic depth (m)		133.46	
Conveynce Total (m3/s)	61618200	Conveynce (m3/s)		61618200	

5.3 Stage and Flow Hydrographs for River Station 10800

At this river station maximum water surface elevation will be 242.89 which will occur at 13.00 pm however maximum peak flow will be at 10458.29 and it will at 16.00 pm on 1 April as shown in Figure (5.3 (a)) below. Remaining all details of cross section is given in Table 5 (b) below.

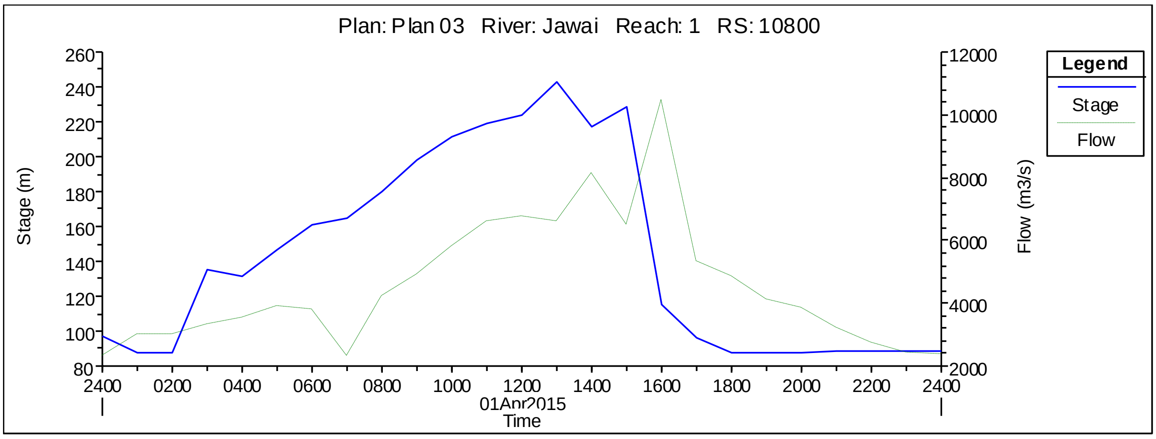

Figure 5.3 (a): Stage and flow hydrographs for river station 10800

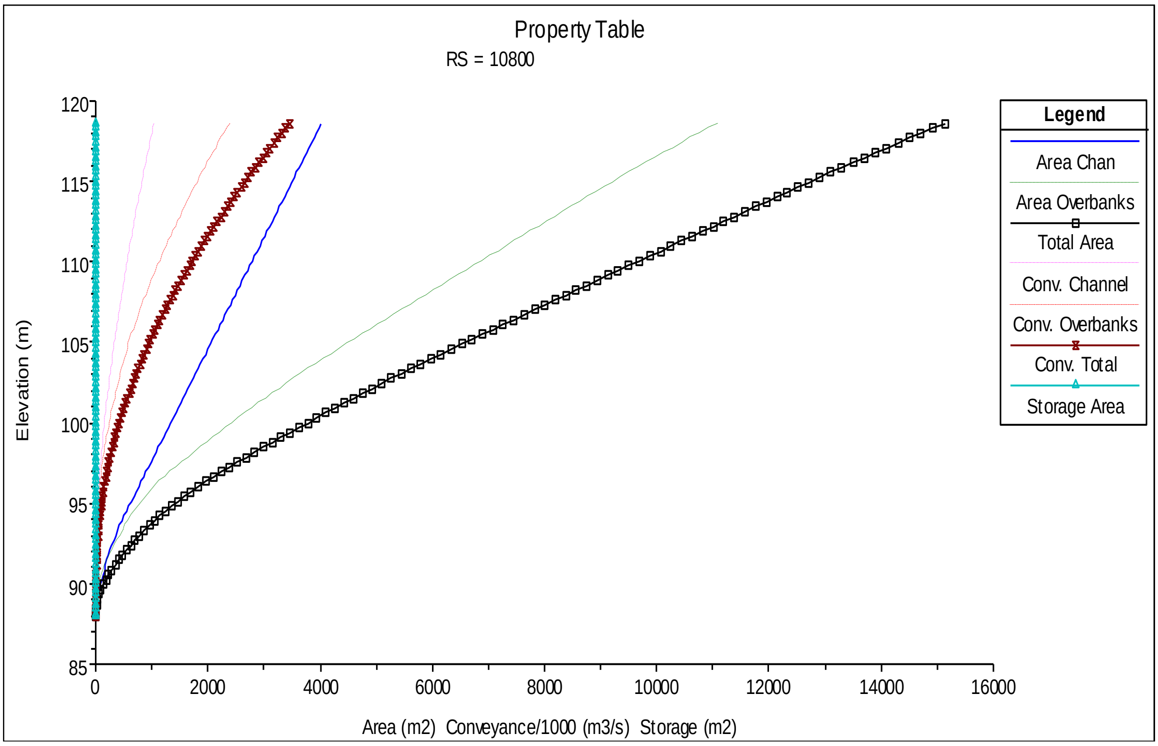

Figure 5.3 (b): Hydraulic property for river station 10800

Table 5 (b): Hydraulics outputs for river station 10800 for maximum water surface

Enegy grad. Elevation (m)	242.42	Element	Left OB	Channel	Right OB
Velocity head (m)	0	Manning constant	0.035	0.035	0.035
Water surface Elevation (m)	242.42	Length of reach (m)	63.37	60.96	63.37

Crit Water surface (m)		Area of flow (m2)	15275.96	79478.19	14521.22
Energy Grad. Slope (m/m)	0	Area (m2)	15275.96	79478.19	14521.22
Toataldischg. (m3/s)	6593.55	Flow (m3/s)	580.93	5463.37	549.24
Top Wid. (m)	762	Top Wid. (m)	107.1	537.37	117.52
total velocity (m/s)	0.06	Avgerage Velocity (m/s)	0.04	0.07	0.04
Maximum channel Dpth (m)	154.46	Hydraulic depth (m)	142.63	147.9	123.56
Conveynce Total (m3/s)	75339020	Conveynce (m3/s)	6637838	62425420	6275754

5.4 Stage and Flow Hydrographs for River Station 400

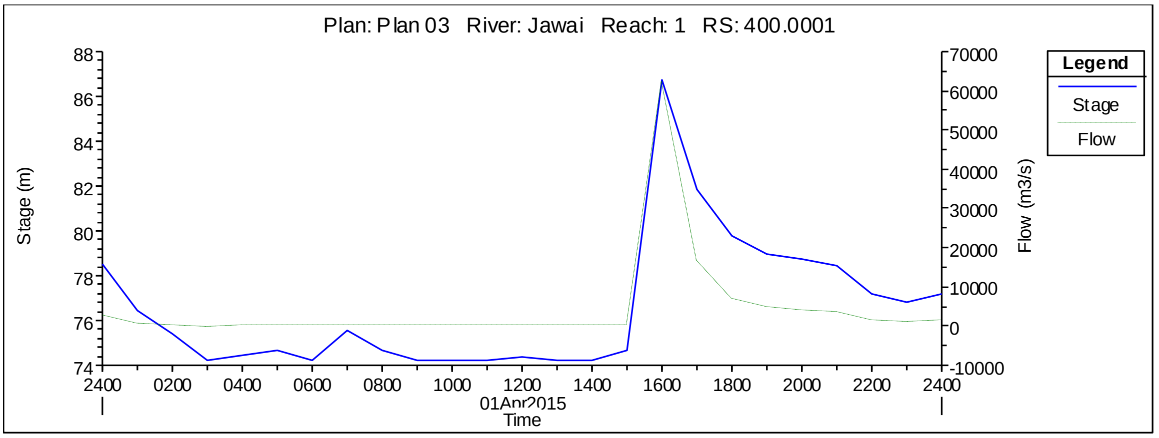

Figure 5.4 (a): Stage and flow hydrographs for river station 400

5.5 Hydraulic Properties of River Station 400

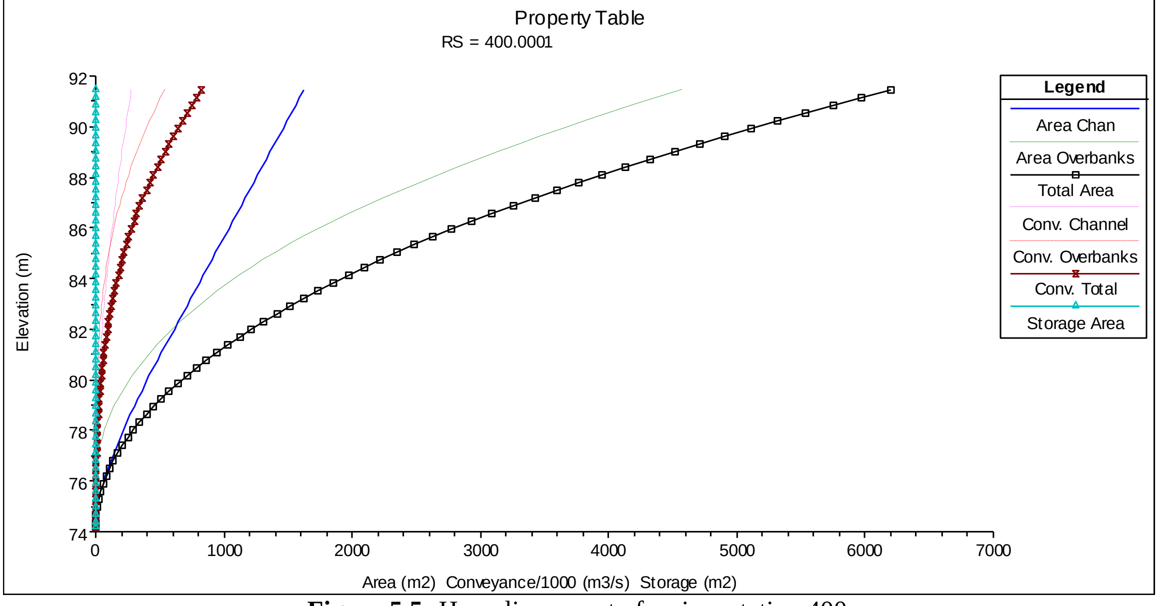

Figure 5.5: Hyraulic property for river station 400

Table 5 (c): Hydraulic output of river station 400 for maximum water surface

Enegy grad. Elevation (m)	109.61	Element	Left OB	Channel	Right OB
Velocity head (m)	22.89	Manning constant	0.035	0.035	0.035
Water surface Elevation (m)	86.72	Length of reach (m)			
Crit Water surface (m)	92.82	Area of flow (m2)	183.1	1118.91	1877.41
Energy Grad. Slope (m/m)	0.03493	Area (m2)	183.1	1118.91	1877.41

Toataldischg. (m3/s)	62285.54	Flow (m3/s)	1712.24	28486.46	32086.84
Top Wid. (m)	537.12	Top Wid. (m)	103.24	107.04	326.83
total velocity (m/s)	19.59	Avgerage Velocity (m/s)	9.35	25.46	17.09
Maximum channel Dpth (m)	12.51	Hydraulic depth (m)	1.77	10.45	5.74
ConvnceTotal (m3/s)	333263.1	Conveynce (m3/s)	9161.5	152418.8	171682.9

5.6 Output of HEC-RAS for Remaining Cross Section

All details of remaining cross section downstream of Jawai Dam are given in Tables below.

Table 5 (d): Hydraulic output for river station 10000 for maximum water surface

Energy grad. Elevation (m)	242.42	Element	Left OB	Channel	Right OB
Velocity head (m)	0	Manning constant	0.035	0.035	0.035
Water surface Elevation (m)	242.42	Length of reach (m)	123.48	121.92	122.03
Crit Water surface (m)		Area of flow (m2)	52308.33	17262.94	45057.33
Energy Grad. Slope (m/m)	0	Area (m2)	52308.33	17262.94	45057.33
Toataldischg. (m3/s)	5675.29	Flow (m3/s)	2552.28	1085.27	2037.74
Top Wid. (m)	762	Top Wid. (m)	342.92	110.1	308.98
total velocity (m/s)	0.05	Avgerage Velocity (m/s)	0.05	0.06	0.05
Maximum channel Dpth (m)	160.43	Hydraulic depth (m)	152.54	156.79	145.83
ConvnceTotal (m3/s)	74964020	Conveynce (m3/s)	33712650	14335190	26916180

Table 5 (e): Hydraulic output for river station 3155 for maximum water surface

Enegy grad. Elevation (m)	113.76	Element	Left OB	Channel	Right OB
Velocity head (m)	0.3	Manning constant		0.035	
Water surface Elevation (m)	113.45	Length of reach (m)	132.36	108.45	97.45
Crit Water surface (m)		Area of flow (m2)		25929.12	
Energy Grad. Slope (m/m)	0.000073	Area (m2)		25929.12	
Toataldischg. (m3/s)	63366.11	Flow (m3/s)		63366.11	
Top Wid. (m)	758.99	Top Wid. (m)		758.99	
total velocity (m/s)	2.44	Avgerage Velocity (m/s)		2.44	
Maximum channel Dpth (m)	36.43	Hydraulic depth (m)		34.16	
ConvnceTotal (m3/s)	7395074	Conveynce (m3/s)		7395074	

Table 5 (f): Hydraulic output for river station 1400 for maximum water suface

Energy grad. Elevation (m)	101.66	Element	Left OB	Channel	Right OB
Velocity head (m)	0.81	Manning constant	0.035	0.035	0.035
Water surface Elevation (m)	100.85	Length of reach (m)	61.03	60.96	61.47
Crit Water surface (m)		Area of flow (m2)	5084.12	5477.61	5742.53
Energy Grad. Slope (m/m)	0.000324	Area (m2)	5084.12	5477.61	5742.53
Toataldischg. (m3/s)	63689.23	Flow (m3/s)	17695.57	24924.38	21069.28
Top Wid. (m)	761.82	Top Wid. (m)	269.39	207.89	284.54
total velocity (m/s)	3.91	Avgerage Velocity (m/s)	3.48	4.55	3.67
Maximum channel Dpth (m)	27.51	Hydraulic depth (m)	18.87	26.35	20.18
ConvnceTotal (m3/s)	3539968	Conveynce (m3/s)	983553.3	1385345	1171070

Table 5 (g): Results of HEC-RAS for each cross section

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
1	12000	Max WS	7300.2	87.64	243.84		243.84	0	0.07	101697.6	762	0
1	11600	Max WS	6946.87	87.64	243.84		243.84	0	0.07	101697.6	762	0
1	11200	Max WS	6593.55	87.64	243.84	95.63	243.84	0	0.06	101697.8	762	0
1	10983.4		Inl Struct									
1	10800	Max WS	6593.55	87.96	242.42		242.42	0	0.07	109275.4	762	0
1	10600	Max WS	6362	86.11	242.42		242.42	0	0.07	111753.5	762	0
1	10400	Max WS	6124.91	84.26	242.42		242.42	0	0.07	114202.7	762	0
1	10000	Max WS	5675.29	83.65	242.42		242.42	0	0.06	114628.6	762	0
1	9600	Max WS	5215.58	88.76	242.42		242.42	0	0.06	114153.2	762	0
1	9400	Max WS	4988.85	86.39	242.42		242.42	0	0.05	115342.4	762	0
1	9200	Max WS	4754.85	84.02	242.42		242.42	0	0.05	116523	762	0
1	8862.06	Max WS	4353.99	80.45	242.42		242.42	0	0.04	121659	778.27	0
1	8313.596	Max WS	3805.9	79.57	242.42		242.42	0	0.04	124473.2	780.21	0
1	8000	Max WS	3487.87	79	242.42		242.42	0	0.04	123478.6	762	0
1	7800	Max WS	3255.78	78.84	242.42		242.42	0	0.03	123570.9	762	0
1	7600	Max WS	3024.53	78.68	242.42		242.42	0	0.03	123663.1	762	0
1	7200	Max WS	2545.77	78.42	242.42		242.42	0	0.03	123792.1	762	0
1	7000	Max WS	2308	78.29	242.42		242.42	0	0.02	123931.5	762	0
1	6800	Max WS	2065.79	78.16	242.42		242.42	0	0.02	124063.1	762	0
1	6400	Max WS	1590.96	77.88	242.42		242.42	0	0.02	124433.8	762	0
1	6271.526	Max WS	1445.95	77.79	242.42		242.42	0	0.02	120421.8	737.14	0
1	5895.481	Max WS	1026.84	78.1	242.42		242.42	0	0.01	111180.8	679.8	0
1	5200	Max WS	224.44	82.66	242.42		242.42	0	0	121545.9	762	0
1	4800	Max WS	2306.96	77.51	228.27		228.27	0	0.03	110265.6	762	0
1	4554.167	Max WS	2123.74	77.43	228.28		228.28	0	0.02	111034.2	762	0
1	4047.689	Max WS	1775.34	77.31	228.28		228.28	0	0.02	111682.4	766.43	0
1	3519.225	Max WS	1401.65	77.2	228.28		228.28	0	0.02	108840.3	747.9	0
1	3337.52	Max WS	1274.44	77.11	228.28		228.28	0	0.01	110890.4	753.45	0
1	3155.815	Max WS	63366.11	77.02	113.45		113.76	0.000073	2.44	25929.12	758.99	0.13
1	2800	Max WS	1166.13	76.25	133.38		133.38	0	0.03	41485.98	762	0
1	2600	Max WS	1119.59	75.83	133.38		133.38	0	0.03	41644.31	762	0
1	2400	Max WS	731.21	75.42	133.38		133.38	0	0.02	41800.82	762	0
1	2000	Max WS	16290.52	74.58	89.66		89.85	0.000168	2.19	8701.02	762	0.18
1	1600	Max WS	15982.85	73.76	89.8		90	0.000174	2.31	8406.21	761.63	0.19
1	1400	Max WS	63689.23	73.34	100.85		101.66	0.000324	4.55	16304.26	761.82	0.28
1	1200	Max WS	63334.99	72.93	100.69		101.57	0.000356	4.77	15704.02	762	0.3
1	800.0001	Max WS	62620.04	73.1	100.63		101.7	0.000481	5.28	14168.48	762	0.34
1	400.0001	Max WS	62285.54	74.21	86.72	92.82	109.61	0.03493	25.46	3179.42	537.12	2.51

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5.7 3-D View of Water Surface Downstream of Jawai Dam

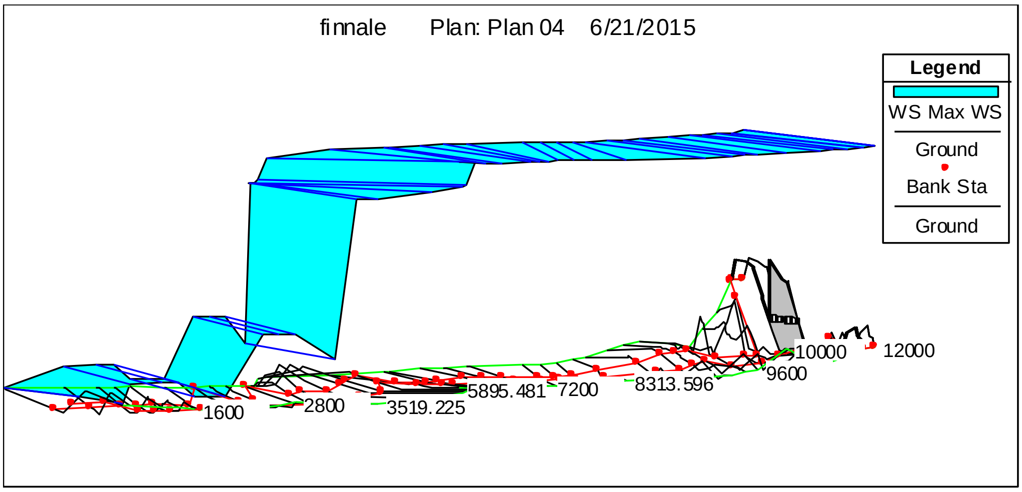

Figure 5.7: 3-D view of water surface elevation of Jawai downstream

From the Figure (5.7) it can be seen that upto 7 km downstream of jawai dam water surface elevation is constant and it is approximately 242.42 meter from there it suddenly reduces to 133 to 128 meter. and flow area is also changes at each cross section and its values is different at at each point.

V. Conclusion

Dam break is comprehensive and complicated process and the actual failure mechanics is difficult to understand. It place Population at risk; However HEC-RAS in concert with HEC-GeoRAS give the capabilities to make a river hydraulics model and simulate a dam failure and also map the resulting flood wave. Moreover GIS is well suited to assist in performing dam failure analysis with the help of available digital terrain data and processing capabilities. Analysis of the hazard associated with dam failure will help in land use planning and in making emergency response plans to help mitigate catastrophic loss to human life and property. Neither present empirical nor physical based models could fully define dam break mechanism and impacts. Dam The dam break tool in HEC-RAS was applied to Jawai dam situated in Sumerpur town, Pali district Rajasthan. And simulation and analysis was made based on geometry data obtained from the help of Google earth. And results were obtained for each cross section which shows that water surface elevation is approximate constant upto 7 km downstream and from there it reduces to 133.38 meter and it ahead it little varies .from the above results it is proved that flow area is different for different cross section for near the dam flow area is 101697 to approximately 12000 square meter and from 7 km downstream it suddenly reduces to 25929.12 to approximately 15000 square meter area. And full breach formation occurs within 12 to 13 hour for assumption taken in 1 hour interval hydrograph for boundary condition in unsteady flow analysis. And from the above report it is proven that results variation depends on assumption used in simulating HEC-RAS model which mostly assumes one dimensional routing. In the above study many assumptions are taken as are necessary for prediction for dam breach as correct results are based on site condition, material used in construction of dam and type of dam, sediment retaining capacity of dam .other assumption used in study of Jawai dam break analysis are breach intitation time and breach bottom width as these are taken from NWS and FERC agencies. And boundary condition was assumed.

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Ankush kumar Gupta,etal. "Dam Break Analysis of JAWAI Dam PALI, Rajasthan Using HEC-RAS." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE),* 17(2), 2020, pp. 43-52.