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Sensitivity Analysis for Dam Breach Parameters Using Different Approaches for Hamrin Dam

Israa Dheyaa Abdulrazzaq*, Qassem H. Jalut and Jasim M. Abbas

Department of Civil Engineering, University of Diyala, 32001 Diyala, Iraq

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ABSTRACT

The prediction of dam's breach geometry crucial in studies of dam breaking. The hydrographs characteristics of flood that resulting from breaking of dam is mainly depend on the geometry of breach and the time formation of breach. Five approaches (Froehlich, Macdonald and Langridge-Monopolis, Von thun & Gillete, USBR and Singh % Snorrason) was used in order to predict dam breach parameters (breach width, breach side slope, breach formation time). The Sensitivity analysis was performed in order to assess the effect of each parameter on the resulting hydrograph of the flood. HEC-RAS model was used to calculate the effect of each parameter on the hydrograph of the flood that resulted. The width of breach (B_{avg}), side slope (z) and formation time of breach (t_f) increased by 25%, 50%, 75% and 100% and decreased by 25%, 50% and 75%, respectively. Flood hydrograph was estimated at the dam site for each case. Sensitivity analysis was performed in order to check the effect of each parameter of breach and time of breaching. Sensitivity analysis was performed with Froehlich method with the mode of overtopping failure and maximum operating level at 107.5 meter above sea level. Result of sensitivity analysis show that peak discharge and time to reach it is adequately sensitive to breach side slope, highly sensitive to the breach formation time and less sensitive to breach width.

1. Introduction

Dams are "structures containing dangerous forces". Dam failures are relatively rare, but when they do occur they can cause severe damage and loss of life and property. Dam breaking can be summarized as a partial or catastrophic failure of the dam resulting in a rapid release of water from reservoir. If the dam breaks, the energy stored backwords the dam is able for causing rapid and unpredictable downstream floods, resulting in loss of life and property damage. Dam failure analysis helps provide enough warnings to the public. So the analysis of dam break and inundation map preparation is very important. Dams are failed due to unforeseen environmental conditions, Poor management or bad engineering since the construction of the first dams. When dams fail they do so often catastrophically due to the large amount of potential energy involved. Dams are a complex structures that are subjected to many forces that can cause the failure. These forces resume their activity throughout the life of the dam, and the fact that it is not necessary to stop the dam safely for several years is a sign that the dam will not fail. One of the forces that cause failure is overtopping. An overtopping is a blockage in the drainage course or as a result of an emergency situation of insufficient drainage capacity [1]. Xiong in (2011)[16] specify the boundary conditions for both upstream and

* Corresponding author.
E-mail address: eng_grad_civil044@uodiyala.edu.iq
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downstream and the height of the gate opening by use the simulation of mixed flow regime. By using hydraulic model HEC-RAS. Other comparative studies of dam break have been performed with HEC-RAS by D. Michael Gee (2010) [5], Tony L. Wahl (July 1998) [7] and Y. Xu1 and L. M. Zhang, Lin Zhang I (2009) [15], Goodel (2005) [6] and Cameron (2008) [2], Basheer, T.A.,(2017) [16], Brunner (2016) [17] with various parameters such a reservoir elevation and parameters of the breach. These studies can be used in order to improve knowledge on this type of cases. Therefore, this study involve a simulation of a case study in Iraq by using HEC-RAS with various break parameters. Hamrin dam project is one of important, strategic and vital projects built on Diyala River in Iraq, which is located around 120 km northeast of Baghdad, Iraq used as a case study in this research. Since small towns are present at the downstream of the dam, the analysis of dam breach should be done as a provision for the reasons that may result because of dam failure (The Ministry of Water Resources 2016, 2017) [11].

2. Definitions of the breach parameters

The term of breach parameters include the breach depth, breach width and the side slope angles. These parameters indicate the time required to initiate and develop of the breach. These parameters briefed below and they show in the figure 1 [3].

Breach depth: it is mentioned as a breach height in many literatures. This is the vertical extent of breach measure from the top of the dam down to the invert of breaching. Some literatures indicate that the head of the reservoir, upon penetration, is measured from the surface of the water of the tank to the upside of the breach.

Breach width: the rate of peak flow and resulting inundation levels downstream of the dam can be largely influenced by the rate of breach width elongation and the final breach width. Case studies usually illustrate either the breach width at the top or bottom of the breaching or the average breaching width.

Breach Side slope factor: The format of the breach opening can be determined by side slope factor, the depth of breach and the width of breach. Accurate prediction of side slope angles is of secondary importance to predicting the depth and width of breaching.

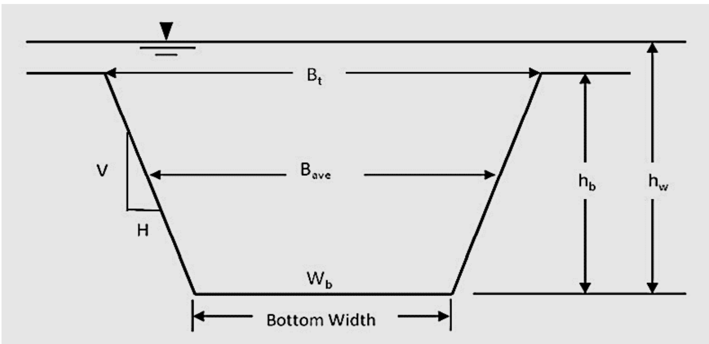

Figure 1. Perfect dam breach parameters

3. Covering approaches

Five of popular empirical methods used to estimate the breach parameters for Hamrin dam within this research. This methods are Froehlich (2008), MacDonald and Langridge-Monopolis, Von Thun & Gillette, (USBR) Bureau of Reclamation and Singh & Snorrason. Singh and Snorrason [9, 10] provided early quantitative guidelines for predicting breach width. Their study was based on data collected from 20-recorded failures of dam. Equation (1) shows the limits of the breach width as a function of the dam height. They discovered that the time of failure ranged from 15 minutes to 1 hour, Equation (2).

$$2h_d \le B \le 5h_d \quad (1)$$

$$0.25 \le t_f \le 1.0 \quad (2)$$

MacDonald and Langridge-Monopolis [8] used data from 42 dam failures to develop associated breach-forming factor relationships. Which can be defined as the production of water volume that passing through the breach (V_{out}) and the depth of water in the reservoir at the failure time, to volume of the material eroded (V_{eroded}) during breaching.

The following is MacDonald's and Langridge-Monopolis equation for the volume of material that eroded and the time of formation of breach, as it reported by Wahl (1998): For an earth fill dams:

$$V_{eroded} = 0.0261(V_{out} * h_w)^{0.769} \quad (3)$$

$$t_f = 0.0179(V_{eroded})^{0.364} \quad (4)$$

For an earth fill with the clay core or rock fill dams:

$$V_{eroded} = 0.00348(V_{out} * h_w)^{0.852} \quad (5)$$

$$W_b = \frac{V_{eroded} - h_b^2(CZ_b + h_b Z_b Z_3/3)}{h_b(C + h_b Z_3/2)} \quad (6)$$

Bureau of Reclamation (USBR) [12] has provided a conservative formula for evaluating the width of the breach of the dam with respect to the depth of the reservoir water Equation (7). This formulation can be taken as a guideline for choosing a final breaching width, Which can be used in risk rating studies, Recommended breaching formation time is 0.011 times breaching width as shown in the equation (8).

$$B = 3h_w \quad (7)$$

$$t_f = 0.011\,B \quad (8)$$

Von Thun and Gillett [13] utilized data gathered from fifty-seven historical failure cases in dams in order to develop- relationship to estimate mean breach as a function of depth of water and a coefficient (C_b) depending on the size of reservoir, as shown in the equation (9) and Table 1.

$$B_{ave} = 2.5\,h_w + C_b \quad (9)$$

Two different groups developed by Von Thun and Gillette for time of breaching development. The first group of equations shows the time of breaching development as a function of the depth of water above bottom of breach:

$$t_f = 0.02h_w + 0.25 \text{(Erosion Resistant)} \quad (10)$$

$$t_f = 0.015h_w \quad \text{(Easily Erodible)} \quad (11)$$

The second group of equations show time of breaching development as a function of depth of water above the breaching bottom and the average width of breaching:

$$t_f = \frac{B_{ave}}{4h_w} \quad \text{(Erosion resistant)} \quad (12)$$

$$t_f = \frac{B_{ave}}{4h_w + 61.0} \quad \text{(Easily erodible)} \quad (13)$$

Table 1. The values of C_b Coefficient with respect to size of the reservoir

Reservoir Size, m^3	**C_b, meters**
$< 1.23 * 10^6$	6.1
$1.23 * 10^6 - 6.17 * 10^6$	18.3
$6.17 * 10^6 - 1.23 * 10^7$	42.7
$> 1.23 * 10^7$	54.9

Froehlich [4] presented one of the recent studies on dam breaching, which can be seen as a further improvement of its breach equations by increasing the sets of data. Froehlich states that the average side slopes are equal to 1H: 1V for the failure mode of overtopping and 0.7H: 1V for the failure mode of piping and failure of seepage. The Froehlich regression equations are shown in table below:

$$B_{ave} = 0.27K_o V_w^{0.32} h_b^{0.04} \quad (14)$$

$$T_f = 63.2\left(\sqrt{V_w/g h_b^2}\right) \quad (15)$$

where: h_d: Height of the dam, B_{ave}: Average breach width, h_b: Height from the top of the dam to bottom of breach, t_f: Breach formation time, h_w: Depth of water above the bottom of the breach, C_b: Coefficient, which is a function of reservoir size, V_{eroded}: Volume of material eroded from the dam embankment, V_{out}: Volume of water that passes through the breach, W_b: Bottom width of the breach, C: Crest width of the top of the dam, Z_b: Breach side slope (Z_b: 1). 0.5 for the Macdonald method, Z_3: (Z_1+Z_2), Z_1: Average slope (Z_1:1) of the upstream face of dam, Z_2: Average slope (Z_2: 2) of the upstream face of dam.

4. Study area

The project of Hamrin dam is one of important, strategic project in Iraq, built on Diyala river which is 10 km away from Diyala dam, and about 120 km northeast of Baghdad, Iraq. The average life expectancy of Hamrin Dam is an average of 100 and 150 years. The Yugoslav company GIK Hidrogradnja (from Sarajevo, now Bosnia and Herzegovina) built the dam and its associated power station in the years 1976-1981. The function of the dam is irrigation, power supply and flood control, the maximum height of the Hamrin Dam is 53 meters. The total length of the dam's body is 3500 meters in the river section of the ancient Diyala River. The height of the dam crest level is 109.50 meters above sea level. The cross section of the Hamrin dam is shown in figure (2). The up-stream and down-stream sides consist of filters and a clay core, and include cladding as well as coarse and fine filters, and from the overflow side blocks of precast concrete. Hydrologically, design the maximum flood potential of Hamrin Dam (70%). The capacity of the reservoir is 3.95 billion cubic meters, and the area of the reservoir is 445 square kilometres, with the same flood level (107.5) meters above sea level [11].

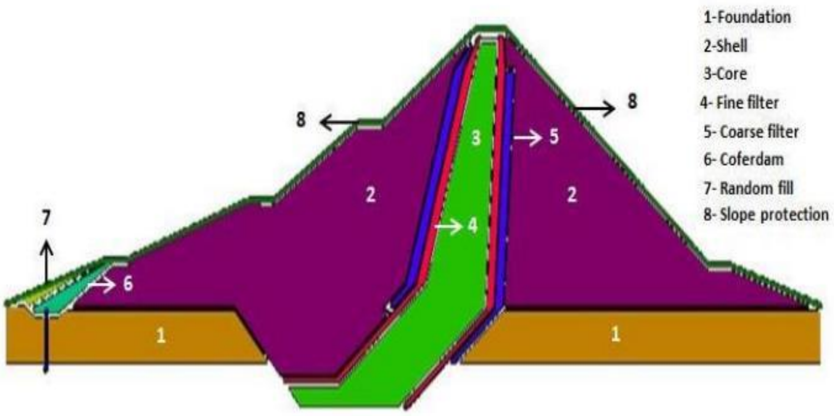

Figure 2. Cross section of Hamrin dam

5. The flood hydrograph

In this study of dam break analysis, the HEC-RAS of version 5.0.7, 2010 is used in order to rout the hydrograph of inflow through the reservoir and the hydrograph of breaching outflow through the downstream of the river. An unsteady flow model was developed for the Hamrin Dam breaching within HEC-RAS. Dam breach analysis involves directing a hydrograph of the outflow from the breached dam throughout the downstream from the dam to the downstream boundary. This will require elevation data for the reservoir and elevation data for the cross section of the river including the flood plain. Within this study, a digital elevation model (DEM) 12.5 * 12.5 was used as an exporter of the elevation data. The dam is modelled within HEC-RAS software using the tool of connection between 2D flow areas and storage areas (SA/2D Area Conn.) instead of modelling the dam as an inline structure since this study focusing two-dimensional flow. Figure (3) shows Hamrin dam profile in HEC-RAS.

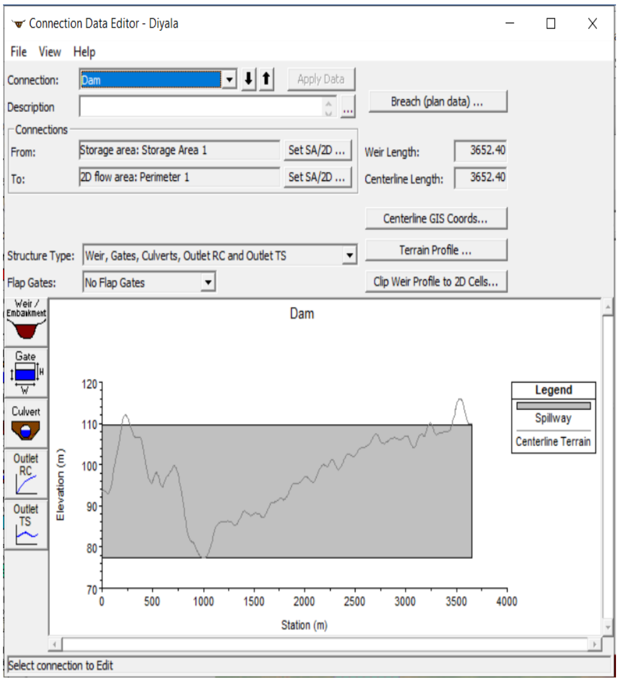

Figure 3. Hamrin dam profile in HEC-RAS

6. Result and discussion

Figure (4) below show the flood hydrograph for Froehlich approach Breach width, side slope and time for breach formation were analysed for Froehlich approach in order to Determine the control parameter of the peak discharge (Q_P) and peak discharge time (T_P).

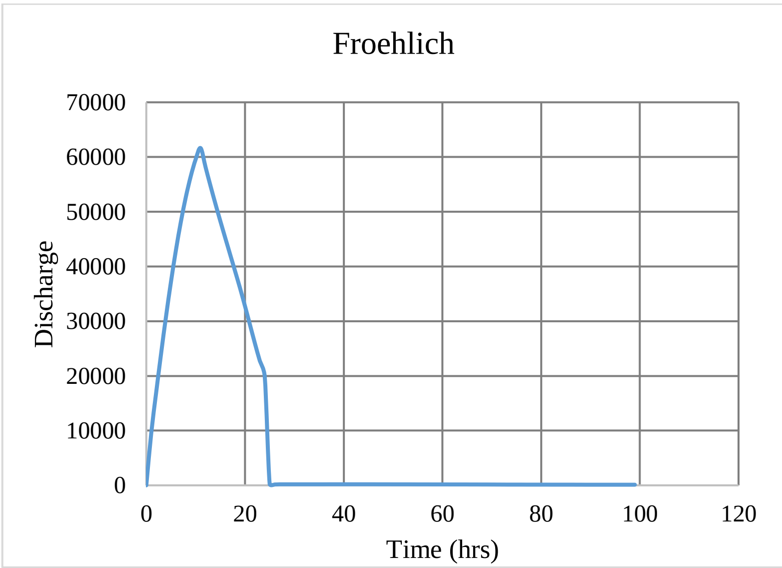

Figure 4. Flood hydrograph for reservoir elevation 107.5 for Froehlich approach

6.1 Breach width

The results of sensitivity analysis show that, when increasing (B_{ave}) with (25%) increases the (Q_P) by (0.21%) and decreasing (B_{ave}) with (25%) decreases the (Q_P) by (0.18%), while the (T_P) remains constant, therefore the effect of breach width for Hamrin dam can be negligible as shown in table (2) and Figure (5) below.

Table 2: Percent change in Q_P and T_P with B_{ave}

B_{ave}	Q_P	$Q_P\%$	T_P (hrs)
+100%	61995.12	0.85	11
+75%	61974.06	0.64	11
+50%	61952.16	0.42	11
+25%	61930.77	0.21	11
0	61909.64	0	11
-25%	61888.54	-0.21	11
-50%	61869.30	-0.40	11
-75%	61847.47	-0.62	11

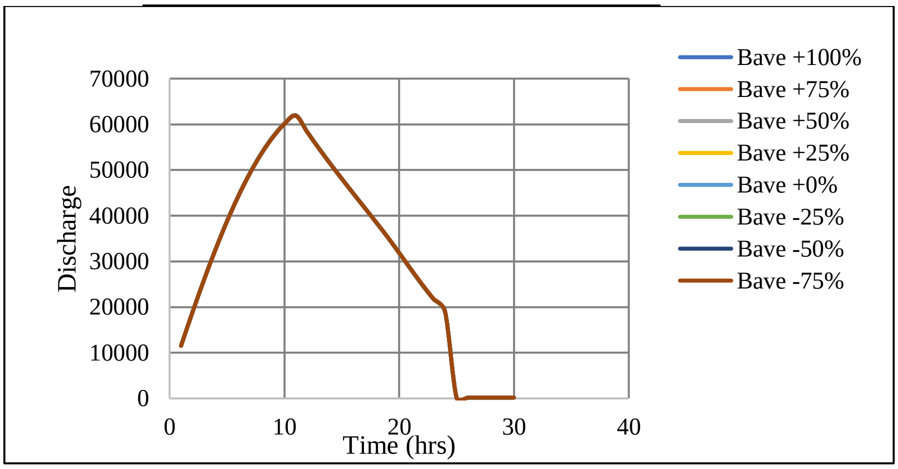

Figure 5. Flood hydrographs for different B_{ave} values at the site of the dam

6.2 Side slope

From the results obtained from this study the Q_P show highly sensitive to change in side slope, from the result showing in Table (3) and Figure (6), increasing the side slope by (50%) leading to increase Q_P by (2.4%) and decreasing side slope by (50%) leading to decrease Q_P by (2.5%).

Table 3: Percent change in Q_P and T_P with breach side slope

Side slope	Q_P	$Q_P\%$	T_P(hrs)
+50%	62138.04	2.4%	11
+0%	61888.54	0	11
-50%	61632.10	-2.5%	11

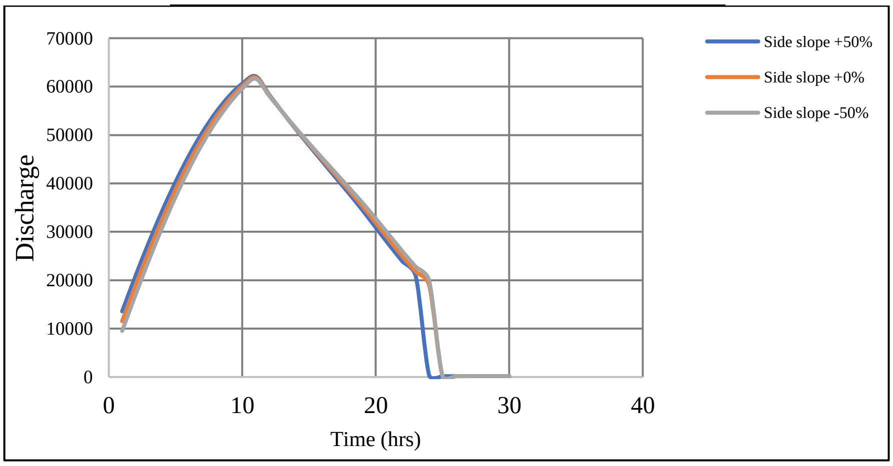

Figure 6. Flood hydrograph for various side slope values at the dam site

6.3 Breach formation time

As shown in Table (4) and Figure (7) below, increase t_f by 50% leading to increase Q_P by (7.9%) and increase T_P too, also decreasing t_f by (50%) leading to decrease Q_P by (3.6%) and decrease T_P too.

Table 4: Percent change in Q_P with breach side slope

t_f	Q_P	$Q_P\%$	T_P (hrs)
+100%	59976.00	3.7%	12
+75%	59598.28	7.0%	12
+50%	60302.10	7.9%	11
+25%	61095.65	7.9%	11
0	61888.54	0	11
-25%	61523.88	-3.6%	11
-50%	61962.10	-4.3%	10
-75%	62897.38	-9.3%	10

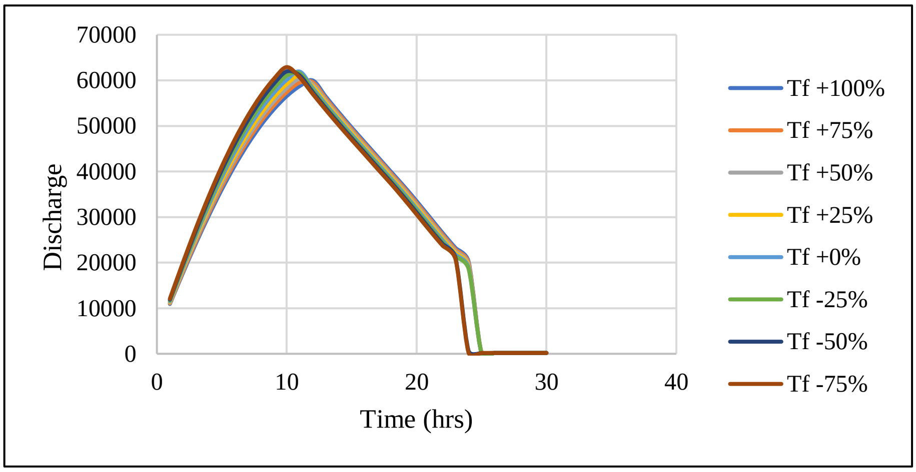

Figure 7. Flood hydrographs for various t_f at the dam site

Figure (8) blow show the flooding area according to Froehlich approach with water surface elevation 107.5m a.s.l. with overtopping failure mode:

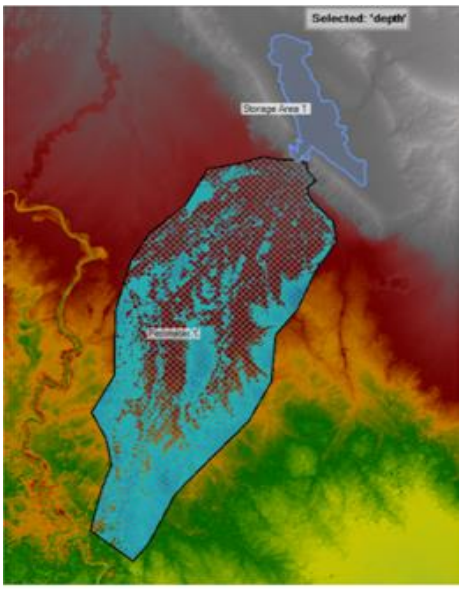

Figure 8. Flooding area according to Froehlich approach

Figures 4, 5, 6 showed that the breach width had a slight effect on the outflow hydrograph (can be neglible), outflow hydrograph is more sensitive to the time of breach formation and highly sensitive to breach side slope on the outflow hydrograph.

7. Conclusion

Result of sensitivity analysis show that the breach width is slight sensitive to the peak discharge and didn't change time for peak discharge, while the flood hydrograph is sensitive to breach side slope. The most effective parameter on peak discharge and peak discharge time was the breach formation time.

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