Dam break analysis using 1D geometry at Jatigede Dam, Sumedang

N Purnama¹, R Jayadi²*, Istiarto²

¹Master Student, Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Indonesia
²Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Indonesia

*Corresponding author: rjayadi@ugm.ac.id

Abstract. Dam breaks can result in flash floods which have enormous destructive power. This destructive force becomes even more significant when the dam break occurs in a dam with a large capacity. An example is the Jatigede Dam, which has a capacity of 1,060 million m³. To determine the flash flood characteristics and potential impact of the collapse of the Jatigede Dam, an analysis of the dam break was carried out using HEC-RAS software. The dam break scenario uses a Probable Maximum Flood (PMF) inflow with the partial opening of two spillway gates in the middle, which causes the dam overtopping. The Froehlich and Von Thun, and Gillette regression methods were used to defining the breach parameters. Based on the dam break analysis, the simulated flash flood of the Von Thun-Gillette method resulted in a higher velocity and lower water surface elevation than the Froehlich method. The difference in the velocity, dimension of the breach shape, water surface elevation, and discharge is caused by the breaching shape and breach formation time.

Keywords: Dam break, flash flood, dam overtopping, breach parameters, breaching shape

1. Introduction

Jatigede dam is one of the big dams in Indonesia with a capacity of 1,060 million m³ which is located in Sumedang district, West Java Province. The main purpose of the Jatigede Dam is to fulfill the irrigation water needs of 90,000 ha rice fields in the district of Cirebon, Indramayu, and Majalengka. The Jatigede reservoir will provide hydroelectric power generation and flood control as well.

The dam built in one area does have various advantages and has a threat [1], [2]. A dam has the inherent risk of breach due to damage of dam body or operational failure of spillway gates. Dam breaches result in a flash flood that has a hugely destructive impact on the environment and threatens the population's lives [3], [4]. The impact of the dam break will become more significant if the dam has a large capacity. The resulting flash flood will also have a very high velocity, and the affected area is extensive.

One of the dam break cases in Indonesia was in 2009, which occurred in the Situ Gintung Dam [5]. The dam break resulted in a flash flood which affected around 300 houses broken and casualties of more than 100 lives. Another case of flash floods due to the dam break has happened in Way Ela river, Maluku [6] and [7]. The dam break occurred in a natural dam formed from landslide material that blocked the
river flow. The flash flood affected around 350 houses and casualties of one life. Before the dam break occurred, the government succeeded in evacuating the population in the downstream area.

Flash floods due to the dam break have different characteristics from floods that occur due to high rainfall. Flash flood is categorized as one of the dangerous disasters because of its mixture and high velocity [8]. The flood characteristics due to the dam break will depend on the height and the capacity of the dam and the breach parameter, such as the width of the breach shape and the breach formation time.

Therefore, the dam break analysis is an essential step in the flood risk reduction effort. The dam break analysis results can be used to develop a disaster risk map as one of the primary considerations in preparing a mitigation plan for flash flood disaster management. This research is a preliminary study to define the flash flood characteristic. This work will be followed by a study on flood risk reduction in the downstream area of the dam, that is in the Cirebon-Indramayu area. Figure 1 shows the roadmap of the mitigation plan disaster caused by dam break.

![Figure 1. The roadmap of the research.](image)

Many dam break analyses have been carried out before to either remodel the dam break disaster in the past or to know the impact and hazard of a dam. The research of dam break analysis of Jatigede Dam has been carried out before with variable approach. Dam break analysis using HEC-RAS with the steady flow was conducted in 2016. The analysis resulted in the maximum water surface elevation of 18.74 m and the average water surface elevation of 3.08 m [9]. The average velocity of the flood is 5.58 m/s. The second research was conducted in the same year with an overtopping and piping scenario at the dam [10]. Furthermore, the maximum velocity of the overtopping flood scenario is 11.38 m/s and 14.18 m/s for a piping scenario. The inundated flood area from the two kinds of research covers the four districts, Majalengka, Sumedang, Indramayu, and Cirebon district.

The exact condition of the spillway gates operation in the previous research was not clearly stated. The trigger of the overtopping scenario of the second research was if one or more gates were open. However, under what conditions or the height of the spillway gates opening, it was not stated that it could trigger the dam break. In addition, the breach parameters and the dimensions of the breach the two previous kinds of research were unknown. Therefore, in this research, the height of the opening spillway gates will be used to decide what kind of gates condition can trigger the overtopping. The regression equation of Froehlich (1995) and Von Thun and Gillette (1990) will be used to define the breach parameter.

2. Materials and Method

2.1. Study Area
The Jatigede Dam is located in the Sumedang district of West Java Province, with the length of the dam is 1.715 m and a height of 110 m. The water in the dam comes from the Cimanuk River, with a watershed area of around 1.462 km². The operation of the Jatigede Dam for flood control purposes is carried out with a spillway equipped with four radial gates with a height of 14.5 m and a total width of 12 m.
2.2. Data Input and Processing
The dam break analysis in this research was carried out using HEC-RAS v6.0 and ArcMap v10.8. ArcMap set the coordinates and combined some of the digital elevation model (DEM) obtained from the DEMNAS website. The DEM data were used to delineate the cross-section of the Cimanuk River since the lack of the actual data of the river. The modeling of the Cimanuk River geometry and surface profile from the dam until the downstream boundary. The Jatigede Dam’s modeling or storage area was carried out using the RAS Mapper of the HEC-RAS. Other model inputs data needed to simulate the dam break are technical data for the Jatigede Dam, such as PMF inflow hydrograph, storage capacity curve, and breach parameters. Figure 2 and Figure 3 depict the PMF inflow hydrograph with the peak discharge of 11,084 m$^3$/s and the storage capacity curve of the Jatigede Dam.

**Figure 2.** The PMF inflow hydrograph of the Jatigede Dam.

**Figure 3.** Reservoir characteristics curve of the Jatigede Dam.

Dam breakage modeling was applied to assume that there is an overtopping or overflow of water over the dam crest. Only two spillway gates in the middle are operated with a partial opening height. The trigger option of the dam break occurrence is water surface elevation. When the water level inside the dam reaches the elevation of +265 m, the breach will start at a designed elevation. This modeling scenario is based on the assumption that the spillway gate function does not work well. After the spillway
gates opening reaches 1.2 m, the gates cannot reach the maximum opening. In contrast, the other two gates at each side cannot be fully opened. The initial reservoir water level is + 250 m.

Two breach parameters will be determined with the same input: the central station of a breach, final bottom elevation, pool elevation and pool volume of failure, and dam erodibility.

2.3. Breach Parameters
Before the dam break occurs, a breach will be formed in the dam body. That breach will become more prominent and causes a dam collapse. For the dam break analysis using HEC-RAS, breach dimensions and breach formation time can be determined outside the software or using a parameter calculator provided by HEC-RAS software. The HEC-RAS parameter calculator can be used to calculate the breach parameters based on the regression equations of MacDonald, Froehlich (1995), Froehlich (2008), Von Thun-Gillette, and Xu-Zhang.

The shape of the breach formation will be described as a trapezium because the minor breach was usually growing into a trapezoidal shape [11]. The breach shape will consist of the width and height of the breach and the side slope in H:V, as shown in Figure 4 [12]. The regression equation of Froehlich (1995) will define the average breach width used to define the bottom width that will be input into HEC-RAS. While the height of the breach is described as a vertical extent from the invert elevation to the top of the dam [12]. In this study, the regression equation of Froehlich (1995) produced the most extensive breach form, while the Von Thun-Gillette regression equation generates the smallest one. Thus, the Froehlich (1995) and Von Thun-Gillette regression equations were selected to be the basis of defining breach parameters. Below is the regression equation to define the breach parameter of Froehlich (1995) and Von Thun-Gillette.

\[
B_{ave} = 0.1803K_o V_w^{0.32} h_b^{0.19} \\
t_f = 0.00254 V_w^{0.53} h_b^{-0.90}
\]

where \(B_{ave}\) is average breach width in meter, \(K_o\) is defined as constant, 1.4 for overtopping failure while 1.0 for piping failure, \(V_w\) is the reservoir volume at the time of failure in a cubic meter, \(h_b\) is the height of the final breach in meter, \(t_f\) is breach formation time in hours. While the side slope should be 1.4H:1V for overtopping failures and 0.9H:1V for other causes (i.e., piping).

Von Thun and Gillette’s equation to define the average breach width and breach formation are [12]:

\[
B_{ave} = 0.25h_w + C_b \\
t_f = 0.02h_w + 0.25
\]
Where $B_{ave}$ is average breach width in meter, $h_w$ is the depth of water above the bottom of the breach in meter, $C_b$ is coefficient, which is defined by the volume of the reservoir, $t_f$ is breach formation time in hours. The side slope for this regression is 0.5H:0.5V. The coefficient of $C_b$ for reservoir volume more than $1.23 \times 10^7$ is 54.9, which is applied for the Jatigede Dam.

3. Result and Discussion

According to the Froehlich regression equation, the bottom breach width is 350 m, and the breach formation time is 6.36 hours. While the result of the Von Thun-Gillette regression equation for the bottom breach width is 129 m, and the breach formation time is 0.99 hours. The final shape of the breach formation using the Froehlich regression is shown in Figure 5 and the Von Thun-Gillette regression is shown in Figure 6.

![Figure 5](image1.png)  
**Figure 5.** The final shape of the dam breach using the Froehlich regression equation.

![Figure 6](image2.png)  
**Figure 6.** The final shape of the dam breach using the Von Thun-Gillette regression equation.

The results of the dam break modeling using the Froehlich regression equation show that the breach occurred within 24 hours from the start of the simulation calculation. The total peak outflow discharge is 53.933 m$^3$/s and occurred 4 hours after the dam started breaching. While analysis of the dam break using the Von Thun and Gillette regression equations gives the results of the start time of the dam break the same as the simulation results using the Froehlich regression equation. What makes a difference is that the total peak outflow discharge is 43.140 m$^3$/s and occurred 1 hour after the dam started breaching.
Figure 7 shows the outflow hydrograph of the dam break using the regression equation of Froehlich and Von Thun-Gillette.

![Outflow hydrograph](image)

**Figure 7.** The outflow hydrograph of Froehlich and Von Thun-Gillette.

Using the Froehlich regression equation, the breach width progress needs 6 hours to reach the final breach width, 350 m. Meanwhile, the Von Thun-Gillette regression equation resulted in 1 hour for the dam to reach the final breach width, 129 m. Figure 8 shows the progress of the breach width from zero until it reaches the final breach width. Figure 9 shows the progress of the flood velocity through the breach area. Before the breaching start, the velocity of the flood was still at 0 m/s. After 24 hours of running after the simulation, both methods show the flood velocity through the breach area. The maximum velocity of Froehlich is 7.66 m/s and occurred after 2 hours since the dam started breaching. At the same time, the maximum velocity of Von Thun-Gillette is 8.31 m/s and occurred after 50 minutes since the dam started breaching.

![Breach width progress](image)

**Figure 8.** Breach width progress of Froehlich and Von Thun-Gillette.
Figure 9. Flood velocity progresses through the breaching area.

The maximum water level (WSE), peak discharge, and the time arrived of the flood in different cross-sections are shown in Table 1. L1 is the Cikopo-Palimanan tollway, L2 is National 1 Street (Pantura Road), and L3 is densely population at Rambatan Kulon, Indramayu district. F (1995) is the analysis result of the Froehlich regression equation, while VTG (1990) is the Von Thun-Gillette regression equation. The distance of the cross-section is measured from the dam to the position of each selected cross-section. The water surface elevation hydrograph at each cross-section is shown in Figure 10 until Figure 12.

Table 1. Flood characteristics at each cross-section.

| Location | Distance (km) | Maximum WSE (m) | Peak Discharge (m³/s) | Time Arrived |
|----------|---------------|-----------------|------------------------|--------------|
|          | F (1995)      | VTG (1990)      | F (1995)               | VTG (1990)   |
| L1       | 36.725        | 63.00           | 53.49                  | 26 h 20 m    | 25 h 29 m |
| L2       | 90.675        | 46.28           | 37.15                  | 28 h 59 m    | 28 h 08 m |
| L3       | 104.075       | 44.74           | 34.59                  | 29 h 37 m    | 28 h 53 m |

Figure 10. The WSE hydrograph at Cikopo-Palimanan tollway.
Figure 11. The WSE hydrograph at Nasional 1 Street (Pantura Road).

Figure 12. The WSE hydrograph at Rambatan Kulon sub-district.

4. Conclusion
The analysis results in this study indicate the possibility of the Jatigede Dam break due to the PMF inflow hydrograph when the spillway gates operation fails. The failure is defined that the opening of two middle gates reaches 1.2 m and the other two gates remain closed. The dimension of the breach size using the Von Thun-Gillette regression equation is smaller than the Froehlich regression equation. The difference in this breaching size resulted in the water outflow, which the WSE by Von Thun-Gillette regression equation is lower than Froehlich. The flood flow velocity using the Von Thun-Gillette regression equation is higher than Froehlich. Therefore, the arrival time of the flood of Von Thun-Gillette is faster than the Froehlich. The difference in the arrival time is caused by the breach formation time using the Von Thun-Gillette regression equation, which occurred in 1 hour while the Froehlich is 6 hours. The differences of those aspects can be seen in three different locations at L1, L2, and L3.

This research is a preliminary study that will be continued to identify the impact of the dam break disaster such as flood depth, potential damage level, total population, residential and public infrastructures affected. The results of this study are expected to be used as consideration in the development of a disaster risk map due to a dam break as an important part of the mitigation plan in the downstream area of the Jatigede Dam.
References
[1] Yi Xiong 2011 A Dam Break Analysis Using HEC-RAS. *J. Water Resour. Prot.* **03** 370-379
[2] Siswanto, Suprapto and Adib L H 2019 Pendekatan GIS dalam Pemodelan Keruntuhan Bendungan Menggunakan HEC-RAS 2D (Studi Kasus Bendungan Logung, Kabupaten Kudus) *Rekayasa J. Sci. Technol.* **12** 112-119
[3] Listyo R 2017 Flood Inundation Prediction of Logung River due to the Break of Logung Dam. *J. Civ. Eng. Forum* **03** 331
[4] Juliastuti, Sofia A, Dadang M, Oki S and Made S 2019 Dam Failure Model to Predict Inundation Hazard Map for Emergency Plan. *Int. J. Eng.* **9** 249-255
[5] Budi H 2018 Analisis Faktor Penyebab Jebolnya Tanggul Situ Gintung. *J. Air Indonesia* **6** 43-51
[6] World Bank 2017 *Meningkatkan Keamanan Bendungan dan Perlindungan Masyarakat Umum Melalui Rencana Tindak Darurat dan Rencana Kontinjensi Berbasis InaSAFE* The World Bank (1818 H Street NW, Washington)
[7] Sutikno H 2014 Countermeasure Against Way Ela Dam Break *J. Acad. Res.* **6** 40-46
[8] Yanuar T K 2013 Hydraulic Simulation of Flash Flood as Triggered by Natural Dam Break. *J. Civ. Eng. Forum* **22** 1319-1325
[9] Mochammad I A 2016 Studi Analisa Penelusuran Banjir Akibat Keruntuhan Bendungan Jatigede Kabupaten Sumedang Jawa Barat. Universitas Brawijaya
[10] Rida D M L 2016 Prediksi Banjir Jika Terjadi Keruntuhan Bendungan Akibat Overtopping dan Piping. Universitas Pendidikan Indonesia.
[11] David C 2008 Embankment Dam Breach Parameters and Their Uncertainties. *J. Hydr. Eng.* **134** 708-1721
[12] HEC 2014 *Using HEC-RAS for Dam Break Studies* U.S. Army Corps of Engineers, Hydrologic Engineering Center (609 Second Street: Davis CA)