Dam Break Analysis of Salomekko Dam Using Zhong Xing HY21

M Ayu¹, P T Juwono¹, R Asmaranto¹, K E Milleanisa¹,*

¹Water Resources Engineering Department, Faculty of Engineering, Universitas Brawijaya, Malang, 65145, Indonesia.

*Corresponding Author: khofihmilleanisa@gmail.com

Abstract: Every Dam must have an emergency plan document in which there is a dam collapse analysis. Based on previous research, it is stated that dam collapse often occurs due to runoff and piping. In this case, the Dam that will be studied is Salomekko Dam, located in Bone Regency. Salomekko Dam is located in the Salomekko Hamlet of Ulu Balang Village, Salomekko Subdistrict, Bone Regency, South Sulawesi Province, which provides water for agricultural irrigation. Analysis of the collapse of the Salomekko Dam was carried out due to overtopping and piping. The stillness of the air overflows through the top of the Dam. At the same time, the piping is caused by seepage in the dam body, which carries the dam material gradually. Analysis of the Salomekko Dam collapse using the Zhong Xing HY21 application can produce maps of flood inundation distribution, flood outflow hydrographs, and flood times. Based on these results, it can also have a hazardous impact to define boundaries of disaster-affected areas.

Keywords: overtopping, piping, Salomekko Dam, Zhong Xing HY21

1. Introduction

Along with the times, the need for water supply is increasing. One way to increase the water resources sector to meet the need for water to support food security is by building physical facilities and infrastructure to support water use. In addition, the construction of a dam is intended to obtain certain benefits. It has the potential for collapse/break that can cause huge losses [1]. Natural phenomena are often difficult to predict. If the Dam is not managed correctly, it will collapse/break, causing massive flooding that can cause huge losses in the downstream area. The same as the previous incident, namely the collapse of the Situ Gintung Dam in 2009, resulted in victims of 98 people dying and 115 missing.

Salomekko Dam is located in Salomekko Subvillage/Hamlet, Ulu Balang Village, Salomekko Subdistrict, Bone Regency, South Sulawesi Province. This Dam is useful for providing water to meet agricultural irrigation needs covering an area of 1722 hectares. In addition to its benefit, the Salomekko Dam also has a very large potential danger in the event of a dam collapse/break. According to research conducted by Costa, the cause of fill type dam break is generally caused by overtopping and piping. Overtopping conditions occur when water runs over the top of the Dam. At the same time, piping is caused by leaks or seepage through the dam body.

Therefore, it is necessary the existence of Dam Break Analysis and the Dam Break Simulation. The analysis of the Salomekko Dam break was carried out due to overtopping and piping using the Zhong Xing HY21 application. This software can produce a map of the distribution of flood inundation to be
used as a guideline for determining the boundaries of potential areas affected by disasters. This guideline is an effort to reduce the impact of losses by knowing the condition of the area affected by the dam break.

2. **Material and Method**

2.1 **Material**

a. **Overview of Study Locations**

The Salomekko Dam is located in Salomekko Hamlet, Ulu Balang Village, Salomekko Subdistrict, Bone Regency, South Sulawesi Province. The Salomekko Dam is located within the Salomekko watershed, a small watershed bordering with the SaloBaruttung and SaloRumpai watersheds in the north, in the west with the SaloBulubulu watershed and the SaloBatakao watershed, in the south with the SaloJawijawi watershed, and in the east with the Bone Gulf. A map from the Bone Regency government on watersheds in Bone Regency is shown in (Figure 1), where the Salomekko River the upstream of the Dam is formed from 3 main tributaries, with the length of the main river to the location of the dam 6.5 km [2]. Salomekko River flows from West to East and empties into Bone Gulf. The length of the Salomekko River from the Dam to the estuary is about 11.8 km. The Salomekko watershed has an area of 40.5 km². While the Salomekko Dam Catchment Area has an area of 13.2 km².

![Figure 1. Watershed Map in Bone Regency](image)

b. **Research data**

- **Annual Maximum Daily Rainfall Data**
  Rain data is used as basic data in calculating the design flood discharge in the Salomekko Reservoir. In this case, one rain station is the closest chosen to represent the Salomekko watershed, namely Salomekko Rain Station (Bicoing). Rain data was used for 20 years from 2000-2019.

- **Salomekko Dam Technical Data**
  Dam technical data is used to determine the characteristics of the Salomekko Dam.

- **Salomekko Reservoir capacity curve**
  To determine the capacity of the Salomekko Reservoir, which functions for calculating flood routing above the spillway so that the reservoir elevation is obtained when it floods.

- **PMP Isohyet Map of Bone Regency, South Sulawesi.**
The PMP map is used to find the Probable Maximum Precipitation (PMP) values that have been described in the Salomekko Dam. This value will be compared with the value of the Probable Maximum Precipitation (PMP) arithmetic to obtain the value of Probable Maximum Flood (PMF) design flood discharge.

- **Topographic maps and Data Elevation Model (DEM)**
  The results of topographic measurements of the river downstream of the Salomekko Dam are used to describe the condition of the downstream of the Dam in the Zhong Xing HY21 application.

- **Indonesian Earth Map / Peta Rupa Bumi Indonesia (RBI) of Bone Regency, South Sulawesi**
  Indonesian Earth Map is used to determine the area affected by the break of the Salomekko Dam, which will later be used to determine the hazard classification of the Salomekko Dam.

- **South Sulawesi Province Road and Building Data**
  Building and road data downstream of the Salomekko Dam in Bone Regency are used to determine the magnitude of the impact due to the collapse/break of the Salomekko Dam.

- **Population Data in the Downstream of Salomekko Dam**
  To determine the classification or level of hazard from the break of the Salomekko Dam.

2.2 **Method**

To obtain a maximum discharge (flood) or a minimum discharge (available discharge), which is a maximum value of an extreme quantity, then the hydrologists must be able to interpret the data available and intended for their research [3]. This hydrological analysis aims to predict the maximum rainfall and flood discharge in the Salomekko Reservoir and their behaviour towards the Salomekko Dam. This study starts from hydrological analysis by testing rain data, frequency analysis, and the test of goodness of fit of distribution. In the frequency analysis of flood discharges in the order they can be checked, the data used is at least 20 years of observational data and studying the characteristics of the existing data distribution function [4]. After obtaining the Probable Maximum Precipitation (PMP) rainfall, then the PMP rain data is converted to discharge using the Synthetic Unit Hydrograph (HSS) method, which in the end the Probable Maximum Flood (PMF) design flood discharge value is obtained.

Furthermore, flood data is simulated through flood routing to obtain reservoir elevation at flood discharge. Through flood routing, it will be known whether the flood discharge can cause overtopping or not. These results will be simulated into the Zhong Xing HY21 program. Through this, a map of the distribution of floods due to the collapse/break of the Salomekko Dam was obtained so that the classification of the flood hazard can be known.

2.3 **Equation**

a. **Design Flood Discharge**

The unit hydrograph is used in the analysis to determine the design flood if the available data is rain data. This method is relatively simple, easy to implement, the data required is simple, and the results of the design provided are quite thorough and significant [5].

Nakayasu Synthetic Unit Hydrograph Equation:

\[
Q_p = \frac{A_R \cdot 0}{3.6(0.3T_p + T_{0.3})} \\
T_p = t_g + 0.8t_r \\
T_{0.3} = \alpha t_g \\
t_g = 0.4 + 0.058 L, \text{ for } L > 15 \text{ Km} \\
t_g = 0.21 L^{0.7}, \text{ for } L < 15 \text{ Km}
\]

With:

- \(Q_p\) = Flood peak discharge (m\(^3\)/sec)
- \(R_o\) = Unit rain (mm)
- \(T_p\) = The grace period from the beginning of the rain until the flood peak (hours)
$T_{0.3} = \text{Time required for discharge to decrease, from peak to 30\% of peak discharge (hours)}$

$A = \text{Area of the catchment to the outlet (km}^2\text{)}$

$t_g = \text{Time lag namely the time between the rain until the flood peak discharge (hours)}.$

$t_r = \text{The length of the effective rain, which is equal to 0.5} \ t_g \ \text{up to} \ 1 \ t_g \ (\text{hours})$

$\alpha = \text{Watershed characteristic constants or hydrograph parameters}$

b. Dam Break

Dam break can be defined as a partial or complete collapse of the Dam or its complementary structures and/or damage resulting in the non-functioning of the Dam [6]. According to the International Commission for Large Dams report, the break of fill type dams generally occurs 38\% due to piping, 35\% due to overtopping, 21\% due to foundation failure, and another 6\% [7]. Therefore, in this study, the dam break was only based on the overtopping scenario (Figure. 2) and/or piping (Figure. 3).

**Figure 2. Illustration of Dam Break Due to Overtopping**

**Figure 3. Illustration of a dam break due to piping**

The overtopping scenario (Figure. 2) depicts that the breaching enlarges over time, from the top of the dam body until reaching the dam foundation [8]. While piping failure (Figure. 3) begins with water seeping through the material, a larger hole is formed to carry more water and erode more material. [9]. Froechlich’s (1987) regression equation for the average breaching width and breaking time is as follows:

\[
B_{\text{BAR}} = 9.5 \ K \ ((V_r \ h_d)^{0.25})
\]

\[
\text{TIME}_{\text{BF}} = 0.8 \ ((V_r / h_d)^{0.5})
\]

With:

$B_{\text{ave}} = \text{average breaching width (m)}$

$K_0 = \text{constant (1.3 for the break of overtopping, 1.0 for piping)}$

$V_r = \text{storage volume at the break (m}^3\text{)}$
Froehlich stated that the height of the break is usually calculated by assuming that the break travels from the top of the Dam to the natural ground level at the site of a dam break[10].

c. Work Steps
1. Testing the data of annual maximum daily rainfall from the average regional rain.
2. Calculating the area's average rain using the Calculated Average Method.
3. Forecasting the design rainfall for the Salomekko Reservoir catchment with frequency analysis.
4. Testing the suitability of the distribution of the design rainfall results with the Chi-Square Test and the Smirnov-Kolmogorof Test.
5. Calculate the amount of PMP.
6. Determine the intensity of hourly rainfall using the PSA 007 method.
7. Calculating the design flood discharge at the Salomekko Reservoir DTA.
8. Conduct a flood investigation due to the PMF design flood discharge in the Salomekko Reservoir DTA in the reservoir on the spillway building.
9. Analysis of the collapse of the Salomekko Dam. This analysis was carried out by simulating the collapse of the Salomekko Dam using the Zhong Xing HY21 application
10. Making inundation maps

d. General Explanation of Zhong Xing HY21 Application
The Zhong Xing HY21 application is software that simulates a dam break and generates an Outflow Hydrograph. The following are the capabilities of the Zhong Xing HY21 application:
• The ability to simulate the influence of a meandering river channel in a fairly wide floodplain.
• Ability to conduct the simulation of subcritical and supercritical flows for the same routing.
• The routing capability of a hydrograph using fast and good dynamic routing for various dam break scenarios.
• Simulation capability is affected by breakwater due to the destruction or break of the Dam that connects the tributary to the river.
• Ability to create the animation of flood travel, flood arrival times, and flood receding times.

The Zhong Xing HY21 application has many advantages that can be used, but this application also has some limitations as follows:
• The results of the simulation cannot be guaranteed 100% accurately.
• The simulation results cannot produce final inundation results or cannot calculate the time for the flood to recede.
• Simulation of the results of a dam break cannot be carried out with only one single process.
• The river channel downstream of a dam basically cannot dry up at the beginning of the simulation, so it is mandatory to have a base flow even though it is very small.

e. Dam Break Simulation Input for Zhong Xing HY21 Application
• Elevation of the dam crest (m)
Elevation of the dam crest is the elevation of the top of the Dam. The peak elevation of the Salomekko Dam is +80 m.
• Reservoir width at the Dam (m)
Reservoir width at the Dam is the span length of the Dam, and the length of the Salomekko Dam is 300 m.
• Initial reservoir water surface elevation (m)
Initial reservoir water surface elevation is the elevation where the initial reservoir water level when the Dam collapses. In this case are +80.00 m for piping and +80.52 m for overtopping.
• Discharge coefficient. for flow over the dam crest (m^{0.5}/s)
Discharge coefficient. For flow over the dam crest is a coefficient whose value is between 1.38 - 2.21.

- **Uncontrolled spillway width (m)**
  Uncontrolled spillway width is the width of the spillway. From the data of Salomekko Dam it is 20 m.

- **Uncontrolled spillway crest elevation (m)**
  Uncontrolled spillway crest elevation is the elevation of the spillway peak; for the Salomekko Dam it is at an elevation of +76.00 m.

- **Uncontrolled spillway discharge coefficient (m0.5/s)**
  Uncontrolled spillway discharge coefficient is a coefficient that has a value between 1.38 - 2.21.

- **H_FAIL**
  H_FAIL is the elevation of the floodwater level when the Dam is destroyed when the water level is at an elevation of 80.00 m for piping and +80.52 m for overtopping.

- **H_BM**
  H_BM is the elevation of the bottom of the reservoir when the Dam begins to collapse. The slope base elevation of the Salomekko Reservoir is at an elevation of +56 m.

- **B_BAR**
  B_BAR is the average fracture width, based on the calculation of the fracture width of Salomekko Dam. The width is 56.27 m for upper piping, 80.05 for middle piping, 84.98 for lower piping overtopping.

- **TIME_BF**
  TIME_BF is the time of failure based on calculations. The collapse time obtained 19,041.28 seconds for top piping, 4,647 seconds for middle piping, 3,659.46 seconds for bottom piping overtopping.

- **RHO_0**
  RHO_0 is the breach nonlinearity formation parameter value of 0-4 for the overtopping scenario is 1, and for piping scenario is 2. While values 3 and 4 are used for tailing dams.

- **SHAPE_Z**
  SHAPE_Z is the fracture slope parameter when the Dam is destroyed; namely for the overtopping scenario the value is 1 because it is assumed that the fracture is in the form of a trapezoid.

- **CPIPE**
  C_PIPE is the Discharge coefficient for orifice flow which is between 0.6-0.8 for the piping scenario.

- **H_PIPE**
  H_PIPE is the piping elevation of the initial failure centre, which is only found in the piping simulation scenario. The value for upper piping is obtained from the spillway peak elevation; it is +76.00 m. Middle piping is obtained from the cofferdam elevation at an elevation; it is +62.00 m. And the lower piping is intake elevation which is + 57 m.

f. **Classification of Dam Hazard Levels**

In this study, the determination of the level of hazard classification uses the guidelines of the Decree of the Director-General of Water Resources No. 257/KPTS/D/201. On the Classification of Dam Hazards where the criteria for determining the level of flood hazard due to the break of a dam use and consider the PenRis (population at risk) parameter towards the distance of a dam, the height of the flood inundation, and the speed/velocity of the flood[11].

3. **Results and Discussion**

3.1 **Hydrological Analysis**

Based on the South Sulawesi PMP map, the PMP value that occurred at the Salomekko Dam location amounted to 770 mm. Meanwhile, based on the PMP Arithmetic from the Hersfield method, the value is greater than the PMP Isohyet, namely 950.387 mm. The results of the PMP Arithmetic from the Hersfield method were chosen for the next calculation process.
Table 1. Recapitulation of the Synthetic Unit Hydrograph Value

| Synthetic Unit Hydrograph Method | Design Flood Discharge (m³/sec) with a Certain Return Period |
|---------------------------------|-------------------------------------------------------------|
| Nakayasu                        | PMF 1000 years: 312.581, 753.862                           |
| Limantara                        | PMF 1000 years: 94.440, 565.528                            |

Based on the results of the calculation of the design flood discharge (Table 2) above, it is stated that the design flood discharge value of the Nakayasu Synthetic Unit Hydrograph method is greater than the Limantara method. The following is figure 4, a flood hydrograph designed by the Nakayasu method.

Figure 4. Nakayasu Method Design Flood Hydrograph

Based on the calculation results of the design flood discharge (Table 2) and (Figure 4), the value used is the flood discharge value of the Nakayasu Synthetic Unit Hydrograph method.

3.2 Flood Routing Through Spillway

Based on the results of Q_{PMF} flood routing (Figure 4), obtained the maximum elevation equal to +80.52 m which has passed the spillway with an elevation of +76.00 m. With the dam peak elevation+80.00 m, so that for Q_{PMF} flood conditions, then the Salomekko Dam is experiencing overtopping.

Figure 5. Graph of Q_{PMF} Inflow and Outflow Relationship on Spillway
The results of these calculations obtained the highest elevation at the maximum $Q_{\text{outflow}}$ is +209.83, while the peak elevation of the Dam is +210. The overtopping condition is the condition of a dam where water overflows over the dam body. It indicates that the Gembong Dam does not experience overtopping due to PMF discharge.

3.3 Zhong Xing HY21 Software Simulation Output
Simulations are carried out for top piping, middle piping, bottom piping, and overtopping scenarios. So that obtained the characteristics of flooding due to the Salomekko Dam break, which is different for each collapse/breaking scenario.

| Breaking Scenario                        | Number of Villages Affected | Inundation Area ($\text{Km}^2$) | Total Peak Outflow Discharge When the Break Occurs ($\text{m}^3/\text{sec}$) |
|-----------------------------------------|-----------------------------|---------------------------------|--------------------------------------------------------------------------------|
| Top Piping of Flood Water Level Condition | 11                          | 13.732                          | 1739.47                                                                        |
| Middle Piping of Flood Water Level Condition | 11                          | 14.478                          | 6412.289                                                                      |
| Bottom Piping of Flood Water Level Condition | 11                          | 14.932                          | 7613.555                                                                      |

Based on the simulation results in each scenario (Table 2), it is found that the overtopping scenario has the greatest flood impact. So from Table 3 below, we get the duration of flooding for each village.

| Village     | Subdistrict  | Maximum Flood Depth (m) | Maximum Flood Speed (m/s) | El. Arrival Time (Hour) | Easing Time (Hour) | Flood Duration (jam) |
|-------------|--------------|-------------------------|---------------------------|------------------------|--------------------|----------------------|
| Bicoing     | Tonra        | 1.669                   | 1.596                     | 6.145                  | 2                  | 96                   | 94                   |
| Bacu        | Tonra        | 5.139                   | 0.316                     | 6.139                  | 2                  | 96                   | 94                   |
| Muara       | Tonra        | 5.360                   | 0.348                     | 13.284                 | 2                  | 96                   | 94                   |
| Teba        | Salomekko    | 4.817                   | 0.159                     | 12.291                 | 2                  | 96                   | 94                   |
| Pancatana   | Salomekko    | 0.617                   | 3.812                     | 42.834                 | 1                  | 1.3                  | 0.3                  |
| Manera      | Salomekko    | 2.801                   | 1.122                     | 3.801                  | 2                  | 96                   | 94                   |
| Bonepetu    | Tonra        | 3.219                   | 1.303                     | 20.111                 | 2                  | 96                   | 94                   |
| Ujunge      | Tonra        | 7.759                   | 0.253                     | 18.908                 | 2                  | 96                   | 94                   |
| Mapatoba    | Salomekko    | 1.254                   | 0.211                     | 2.254                  | 7                  | 96                   | 89                   |
| Malimongeng | Salomekko    | 0.858                   | 0.089                     | 1.860                  | 14                 | 96                   | 82                   |
| Tarasu      | Kajuara      | 0.860                   | 0.094                     | 1.860                  | 20                 | 96                   | 76                   |

So from Table 4 below are the results of the flood hazard classification level for the affected areas due to the collapse of the Salomekko Dam, based on the results of the collapse of Salomekko Dam with the overtopping scenario has the worst impact using the Zhong Xing HY21 application. The determination of the level of hazard classification is based on the Decree of the Director-General of Natural Resources Number 257/KPTS/D/2011, concerning Guidelines for Classification of Dam Hazards.
Table 4. Classification of Flood Hazard Levels Based on Population Affected by Risk

| No | Village  | Distance From Dam (km) | Affected House | Number of Population Affected by Risk (People) | Hazard Classification | Information     |
|----|----------|------------------------|----------------|-----------------------------------------------|-----------------------|-----------------|
| 1  | Bicoing  | 2.618                  | 164            | 820                                           | 4                     | Very High Hazard|
| 2  | Bacu     | 5.250                  | 108            | 540                                           | 4                     | Very High Hazard|
| 3  | Pancatana| 6.520                  | 44             | 220                                           | 4                     | Very High Hazard|
| 4  | Muara    | 6.170                  | 79             | 395                                           | 4                     | Very High Hazard|
| 5  | Bonepetu | 7.180                  | 0              | 0                                             | 1                     | Low Hazard      |
| 6  | Ujunge   | 7.450                  | 0              | 0                                             | 1                     | Low Hazard      |
| 7  | Tebba    | 6.380                  | 36             | 180                                           | 4                     | Very High Hazard|
| 8  | Manera   | 6.913                  | 82             | 410                                           | 4                     | Very High Hazard|
| 9  | Mapatoba | 9.120                  | 0              | 0                                             | 1                     | Low Hazard      |
| 10 | Malimongeng | 10.190               | 0              | 0                                             | 1                     | Low Hazard      |
| 11 | Tarasu  | 11.090                 | 0              | 0                                             | 1                     | Low Hazard      |

Based on the classification of the level of flood hazard due to overtopping conditions (Table 4), it was found that there are six villages namely Bicoing Village, Bacu Village, Pancatana Village, Muara Village, Bonepetu Village, Tebba Village, and Manera Village which are classified as very high hazard. Meanwhile, the other five villages, namely Bonepetu Village, Ujunge Village, Mapatoba Village, Malimongeng Village, and Tarasu Village, are a low hazard because they are not densely populated. The total population at risk in the downstream of the Salomekko Dam has a total population of 2565 people.

Figure 6. Map of Flood Inundation due to Overtopping Conditions
On the map of the distribution of flood inundation due to overtopping conditions (Figure 5) is spread over 11 villages. Red flood inundation indicates a water depth of more than 2 m. It shows that flooding due to the Dam's break from the overtopping conditions will have the greatest impact.

4. Conclusion
From the analysis and simulation results that have been carried out on the collapse of the Salomekko Dam. So, it can be concluded as follows:

a. Based on the simulation, it was found that the flood discharge with a Q_{PMF} return period is 753.862 m³/s could cause the Salomekko Dam to experience the break due to overtopping.

b. The collapse of Salomekko Dam is assumed due to piping and overtopping. Based on the results of Zhong Xing HY21 application, the greatest risk of impact is caused by overtopping conditions with flood characteristics, including the peak outflow discharge at the collapse of 8,357.593 m³/s, the highest flood depth is 7.759 m, maximum flood speed is 3.812 m/s, The highest flood water level is 42.834 m, and the longest flood duration is 94 hours.

c. The collapse of the Salomekko Dam due to piping and overtopping caused flooding to spread to 11 villages, namely Bicoing Village, Bacu Village, Pancatana Village, Muara Village, Bonepetu Village, Ujunge Village, Tebba Village, Manera Village, Mapatoba Village, Malimongeng Village, and Tarasu Village. The flood was spread over an area of inundation due to upper piping being 13.732 km², middle piping being 14.478 km², lower piping being 14.932 km², and overtopping is 15.694 km². So, the largest inundation area is due to overtopping conditions.

d. The collapse of the Salomekko Dam due to overtopping conditions is the biggest threat to the villagers downstream of the Dam. Based on the number of residents exposed to risk, overtopping conditions can cause six villages, namely Bicoing Village, Bacu Village, Pancatana Village, Muara Village, Bonepetu Village, Tebba Village, and Manera Village, which are classified as very high hazard. Meanwhile, the other five villages, namely Bonepetu Village, Ujunge Village, Mapatoba Village, Malimongeng Village, and Tarasu Village, are a low hazard because they are not densely populated.

e. The total population at risk in the lower reaches of the Salomekko Dam has a total population of 2565 people.

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