Dam Break Analysis of Gembong Dam Using Zhong Xing HY21

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Abstract: Dams are a form of effort to conserve or protect water resources. The function of the Dam as a reservoir for water, irrigation, power generation, and flood control. However, in addition to its huge benefits, dam construction also can endanger the community's safety, namely in the form of dam breaks. The main causes of dam break are overtopping and piping. So that analysis is needed related to dam break to minimize the impact. Based on the Zhong Xing HY21 software, the most severe impact of the break of the Gembong Dam was due to overtopping using the QPMF design flood of 724.142 m³/s. It resulted in an inundation area of 54.682 km² with a maximum inundation height of 5.129 m. As a result of the break of the Gembong Dam, 37 villages downstream of the Gembong Dam were flooded. There are 80.819 people affected by this risk. It is stated that all affected villages are at the 4th hazard classification level or very high hazard.

Keywords: Gembong Dam, overtopping, piping, Zhong xing HY21

1. Introduction

Every living thing needs water for its survival. However, the clean water crisis is hitting several countries in the world, including Indonesia. The construction of high-rise buildings and community settlements that do not pay attention to the environment, illegal logging and no effort to control nature conservation, and the disposal of factory waste and domestic waste directly into rivers without being processed first are human activities that make the water crisis worse [1].

Dams are one form of effort to conserve or protect water resources. But behind the benefits obtained from dams, dams also have a large potential hazard in the possibility of a dam break. Regulation of the Minister of Public Works and Public Housing No. 27 of 2015 defines that “Dam break is a partial or complete collapse of the dam or its complementary structures and/or damage resulting in the non-functioning of the dam” [2]. The disaster does not only occur in the location around the structure but covers the downstream area of the Dam and can cause huge losses.

Due to the age of the Gembong Dam and the growing downstream area, an analysis of dam break is carried out. Therefore, it is necessary to conduct research related to the dam break analysis as a form of the Emergency Action Plan to determine the risk of Dam and disaster hazards in the areas affected. So that if this catastrophic occurs, it can minimize the losses.
2. Material and Method

2.1 Material
Gembong Dam is located in Gembong Village, Gembong District, Pati Regency, Central Java Province. Gembong Dam is located approximately 15 km southeast of Pati City. Gembong Dam was built from 1930 to 1933 by the Dutch colonial government, which included Embankment Dam. Gembong Dam can accommodate water under normal conditions as much as ± 9,500,000 m³ and the source of Gembong Dam water comes from the main Kali Sani River. Gembong Dam functions as a reservoir for water in the rainy season and irrigates technical irrigation of 923 hectares of rice fields.

The data needed to support this study are as follows:

a. Rainfall Data
Rainfall data was used for 16 years, starting from 2004 – 2019. This rainfall data will then be used for hydrological analysis to calculate the design flood discharge at the Gembong Dam. In this case, the annual maximum daily rainfall data is obtained from 2 rain stations, namely Gembong Station and Gunung Rowo Station.

b. Dam Technical Data
Gembong Dam technical data to determine the characteristics of the Dam in the form of dam height, dam capacity, and dam dimensions. Gembong Dam technical data will be required in the calculation of flood routing and determination of failure parameters.

c. Capacity Curve of Reservoir
The capacity curve of the reservoir is a description of the storage in the Gembong Reservoir used in flood routing.

d. Central Java PMP Isohyet Map
The PMP Isohyet map was used as a control of the PMP rainfall obtained from the calculation. The two PMP rains will be compared, and the larger value is taken.

e. DEM Map
Used to perform simulations on the Zhong Xing HY21 software.

f. Indonesian Earth Map / Peta Rupa Bumi Indonesia (RBI)
This map is useful for overlaying when the flood output from the Zhong Xing HY21 already exists to find out which villages are affected by flooding as a result of the dam break.

g. Population Data
This data is useful as reference data for the number of people affected in an area affected by floods. The data used is the population in 2020.

2.2 Method
This study uses two rain stations, namely Gembong Station and Gunung Rowo Station. Before the rainfall data is used in the hydrological analysis, the consistency of the rainfall data is tested using the RAPS (Rescaled Adjusted Partial Sums) method. Before looking at the regional average rainfall, an outlier test must be run on this data first. Then look for the regional average rainfall using the Arithmetic method. After that, perform the frequency analysis calculation using the Normal, Log normal, Log Pearson III, and Gumbel methods. Next, the goodness of fit of the distribution was tested using two methods, namely the Smirnov-Kolmogorov test and the Chi-Square test to determine the design rainfall to be used [3].

The next thing is to calculate the flood discharge, designed using Nakayasu Synthetic Unit Hydrograph and Gama I Synthetic Unit Hydrograph. After calculating the flood discharge, the next step is to calculate the flood routing to determine whether the Dam is overtopping or not. After conducting the hydrological calculation analysis, the simulation is conducted using the Zhong Xing HY21 software. The results obtained are in the form of a flood inundation map, arrival time, peak time, depth, velocity, and elevation of the flood and can produce a cross-section. From the distribution of flood inundation, it can be seen which villages are affected.
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 accurate [4]. The following is the equation for flood peak discharge in Unit Hydrograph (UH) at Nakayasu Synthetic Unit Hydrograph [5]:

\[
Q_p = A \cdot R_o \\
T_p = t_g + 0.8t_r \\
T_{0.3} = \left( t_g \right) \\
t_g = 0.4 + 0.058L, \text{ for } L > 15 \text{ Km} \\
t_g = 0.21L^{0.7}, \text{ for } L < 15 \text{ Km}
\]

With:

- \( Q_p \): Flood peak discharge (m³/sec)
- \( R_o \): Unit rain (mm)
- \( T_p \): The grace period from the beginning of the rain until the flood peak (hours)
- \( T_{0.3} \): Time required for discharge to decrease, from peak to 30% of peak discharge (hours)
- \( A \): Area of the catchment to the outlet (km²)
- \( t_g \): Time lag namely the time between the rain until the flood peak discharge (hours).
- \( t_r \): The length of the effective rain, which is equal to 0.5 \( t_g \) up to 1 \( t_g \) (hours)
- \( \left( \right) \): Watershed characteristic constants or hydrograph parameters

b. Dam Break

Before the dam experiences total break, it is preceded by the occurrence of breaching. Froehlich's regression equation for the average breaching width and breaking time is as follows:

\[
B_{BAR} = 9.5 \cdot K_0 \cdot ((V_r \cdot h_d)^{0.25}) \\
TIME_{BF} = 0.8 \cdot ((V_r / h_d)^{0.5})
\]

With:

- \( B_{ave} \): average breaching width (m)
- \( K_0 \): constant (1.3 for the break of overtopping, 1.0 for piping)
- \( V_r \): storage volume at the break (m³)
- \( h_d \): breaching final height (m)
- \( T_f \): breaking time (sec)

Froehlich stated that the mean side slope should be 1.0H:1V for overtopping break and 0.7H:1V for other breaks (such as piping) [6].

c. Dam Hazard Classification

Determination of class or class level based on the number of population at risk/PenRis (population exposed to risk, namely residents or people living in areas affected by flood inundation). The population at risk is the entire population in the downstream area of the Dam who is threatened or affected by danger in the event of a dam break. The population at risk can be identified from inundation maps resulting from the studies of dam break. The level of dam hazard is obtained from the relationship between the number of populations at risk in life/person or the Head of the Family/KK (1 KK = 5 people) and the distance of the population at risk location from the dam [7] [8].

3. Results and Discussion

3.1 Hydrological Analysis

Based on the value of the Java Isohyet PMP Map Sheet 2, the PMP that occurred at the Gembong Dam location amounted to 750 mm/day. The highest PMP value is used in the next calculation, namely from the PMP arithmetic equal to 944.75 mm/day.
Table 1. Recapitulation of the Synthetic Unit Hydrograph Value

| Synthetic Unit Hydrograph Method | Design Flood Discharge (m$^3$/sec) with a Certain Return Period |
|----------------------------------|---------------------------------------------------------------|
|                                 | 1000 years | PMF                                   |
| Nakayasu                        | 508,580    | 724,142                              |
| Gama I                          | 361,484    | 531,816                              |

Based on the analysis that has been conducted (Table 1) using two methods, namely the Nakayasu synthetic unit hydrograph method and the Gama I synthetic unit hydrograph method, it was found that which will be used for the analysis of the Gembong Dam break is by using the Nakayasu synthetic unit hydrograph method, because the resulting PMF flood discharge is greater than the result of the PMF design flood discharge from the Gama I method by considering the dangers resulting from the break of the Gembong Dam.

Figure 1. Graph of $Q_{PMF}$ Inflow and Outflow Relationship on Spillway

3.2 Flood Routing Through Spillway
Flood routing through the spillway aims to determine the water level that overflows when a flood discharge passes through the spillway. In the analysis of the Gembong Dam break, the results of the flood routing will then be used as the basis for determining the condition of a dam, whether a dam is overtopping or not.

The results of these calculations obtained the highest elevation at the maximum $Q_{outflow}$ 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
Based on the analysis that has been carried out through the running process using the Zhong Xing HY21 program, it is found that the Overtopping scenario of flood water levels has the widest impact, namely 54.682 km$^2$ and produces the highest outflow discharge at 11,564.861 m$^3$/sec compared to other scenarios and conditions. More detailed conditions can be seen in table 2.

Table 2. Comparison of the Output Results of each Scenario from Zhong Xing HY21 Program

| Breaking Scenario                  | Number of Villages Affected | Area (km$^2$) | Total Peak Outflow Discharge When the Break Occurs (m$^3$/sec) |
|------------------------------------|-----------------------------|---------------|---------------------------------------------------------------|
| Top Piping of Flood Water Level    | 37                          | 53.164        | 7,897,762                                                    |
| Middle Piping of Flood Water Level| 37                          | 53.562        | 9,942,340                                                    |
| Bottom Piping of Flood Water Level| 37                          | 54.039        | 10,375,790                                                   |
| Overtopping                        | 37                          | 54.682        | 11,564,861                                                   |
The simulation process is carried out according to the parameters and scenarios that have been determined by entering all the required data. As for the results of the running process using the Zhong Xing HY21 Software, it was found that there were 37 villages affected by flooding due to the Gembong Dam break. The village data and the location of the coordinates are as follows:

| No | Village       | Distance From Dam (km) | Flood Depth (m) | Flood Velocity (m/sec) | Flood Arrival Time (The -th Hour) | Time of Flood Receding (The -th Hour) | Flood Duration |
|----|---------------|------------------------|----------------|------------------------|------------------------------------|----------------------------------------|----------------|
| 1  | Wonosekar     | 0.57                   | 5.129          | 11.640                 | 1                                  | 96                                     | 95             |
| 2  | Pohgading     | 0.15                   | 3.289          | 13.120                 | 1                                  | 17                                     | 16             |
| 3  | Semirejo      | 1.82                   | 3.672          | 11.252                 | 1                                  | 5                                      | 4              |
| 4  | Tamanansari   | 5.90                   | 1.011          | 6.263                  | 1                                  | 12                                     | 11             |
| 5  | Mulyoharjo    | 8.86                   | 0.821          | 0.457                  | 3                                  | 4                                      | 1              |
| 6  | Tambaharjo    | 10.17                  | 0.677          | 0.149                  | 2                                  | 3                                      | 1              |
| 7  | Sidokerto     | 8.78                   | 0.743          | 0.458                  | 3                                  | 4                                      | 1              |
| 8  | Mukitharjo    | 6.67                   | 1.003          | 1.798                  | 2                                  | 26                                     | 24             |
| 9  | Purworejo     | 15.49                  | 0.382          | 0.171                  | 7                                  | 26                                     | 19             |
| 10 | Kutoharjo     | 10.16                  | 0.996          | 1.280                  | 2                                  | 96                                     | 94             |
| 11 | Widorokandang | 14.07                  | 1.186          | 0.680                  | 3                                  | 96                                     | 93             |
| 12 | Winong        | 8.67                   | 1.105          | 0.145                  | 3                                  | 4                                      | 1              |
| 13 | Sarirejo      | 12.02                  | 1.670          | 1.339                  | 3                                  | 96                                     | 93             |
| 14 | Pati Lor      | 10.41                  | 0.056          | 0.183                  | 3                                  | 3                                      | 0              |
| 15 | Parenggan     | 10.99                  | 0.735          | 0.039                  | 3                                  | 96                                     | 93             |
| 16 | Gerian        | 12.97                  | 1.370          | 0.976                  | 3                                  | 18                                     | 15             |
| 17 | Tondomulyo    | 16.05                  | 1.757          | 0.198                  | 4                                  | 96                                     | 92             |
| 18 | Puri          | 8.93                   | 0.731          | 0.192                  | 2                                  | 96                                     | 94             |
| 19 | Ngarus        | 10.04                  | 0.989          | 0.647                  | 2                                  | 96                                     | 94             |
| 20 | Sugiharjo     | 14.36                  | 1.321          | 0.161                  | 3                                  | 96                                     | 93             |
| 21 | Karangrowo    | 14.78                  | 1.541          | 0.255                  | 3                                  | 96                                     | 93             |
| 22 | Sidoaharjo    | 12.11                  | 1.209          | 1.385                  | 2                                  | 96                                     | 94             |
| 23 | Patiwetan     | 11.38                  | 0.794          | 1.672                  | 2                                  | 96                                     | 94             |
| 24 | Patikidul     | 10.53                  | 1.018          | 0.711                  | 2                                  | 13                                     | 11             |
| 25 | Ngastorejo    | 14.65                  | 1.191          | 0.182                  | 3                                  | 96                                     | 93             |
| 26 | Dengkek       | 12.92                  | 2.348          | 1.183                  | 2                                  | 96                                     | 94             |
| 27 | Plangitan     | 9.74                   | 0.544          | 0.038                  | 2                                  | 3                                      | 1              |
| 28 | Semampir      | 12.2                   | 0.364          | 0.217                  | 2                                  | 3                                      | 1              |
| 29 | Blaru         | 11.16                  | 2.969          | 0.829                  | 2                                  | 96                                     | 94             |
| 30 | Kedungmulyo   | 14.25                  | 2.370          | 0.136                  | 3                                  | 96                                     | 93             |
| 31 | Mustokoharjo  | 12.92                  | 1.582          | 0.764                  | 2                                  | 96                                     | 94             |
| 32 | Gajahmati     | 12.66                  | 1.582          | 0.764                  | 3                                  | 23                                     | 20             |
| 33 | Panjunan      | 11.99                  | 0.627          | 1.324                  | 2                                  | 22                                     | 20             |
| 34 | Banjarsari    | 13.82                  | 0.425          | 0.290                  | 4                                  | 41                                     | 37             |
| 35 | Langenharjo   | 13.05                  | 0.074          | 0.047                  | 4                                  | 8                                      | 4              |
| 36 | Babalan       | 13.77                  | 1.037          | 0.511                  | 6                                  | 96                                     | 90             |
| 37 | Tanjang       | 13.67                  | 2.387          | 0.147                  | 6                                  | 96                                     | 90             |

3.4 Dam Hazard Level Classification

The following are the results of the provisions for the determination of the level of flood hazard classification towards areas affected by the Gembong Dam break, which refers to the results of flood inundation due to the break of the Gembong Dam with the Overtopping scenario of flood water level.
conditions that have the worst impact using the Zhong Xing HY21 program and the determination of the level of hazard classification.

Table 4. Classification of Flood Hazards Based on Population Affected by Risk

| No | Village      | Distance From the Dam Axes (Km) | Number of Population Affected by Risk (People) | Hazard Level | Information          |
|----|--------------|---------------------------------|-----------------------------------------------|--------------|----------------------|
| 1  | Wonosekar    | 0.57                            | 234                                           | 4            | Very High Hazard     |
| 2  | Pohgading    | 0.15                            | 71                                            | 4            | Very High Hazard     |
| 3  | Semirejo     | 1.82                            | 1881                                          | 4            | Very High Hazard     |
| 4  | Tamansari    | 5.9                             | 2905                                          | 4            | Very High Hazard     |
| 5  | Mulyoharjo   | 8.86                            | 1844                                          | 4            | Very High Hazard     |
| 6  | Tambaharjo   | 10.17                           | 320                                           | 4            | Very High Hazard     |
| 7  | Sidokerto    | 8.78                            | 4915                                          | 4            | Very High Hazard     |
| 8  | Muktiharjo   | 6.67                            | 5378                                          | 4            | Very High Hazard     |
| 9  | Purworejo    | 15.49                           | 830                                           | 4            | Very High Hazard     |
| 10 | Kutoharjo    | 10.16                           | 7031                                          | 4            | Very High Hazard     |
| 11 | Widorokandang| 14.07                           | 1461                                          | 4            | Very High Hazard     |
| 12 | Winong       | 8.67                            | 5111                                          | 4            | Very High Hazard     |
| 13 | Sarirejo     | 12.02                           | 2669                                          | 4            | Very High Hazard     |
| 14 | Pati Lor     | 10.41                           | 6754                                          | 4            | Very High Hazard     |
| 15 | Parenggan    | 1099                            | 1332                                          | 4            | Very High Hazard     |
| 16 | Geritan      | 12.97                           | 1379                                          | 4            | Very High Hazard     |
| 17 | Tondomulyo   | 16.05                           | 483                                           | 4            | Very High Hazard     |
| 18 | Puri         | 8.93                            | 5702                                          | 4            | Very High Hazard     |
| 19 | Ngarus       | 10.04                           | 2903                                          | 4            | Very High Hazard     |
| 20 | Sugiharjo    | 14.36                           | 1866                                          | 4            | Very High Hazard     |
| 21 | Karangrowo   | 14.78                           | 499                                           | 4            | Very High Hazard     |
| 22 | Sidoharjo    | 12.11                           | 2514                                          | 4            | Very High Hazard     |
| 23 | Patiwratan   | 11.38                           | 878                                           | 4            | Very High Hazard     |
| 24 | Patikidul    | 10.53                           | 4673                                          | 4            | Very High Hazard     |
| 25 | Ngastorejo   | 14.65                           | 111                                           | 4            | Very High Hazard     |
| 26 | Dengkek      | 12.92                           | 1857                                          | 4            | Very High Hazard     |
| 27 | Plangitan    | 9.74                            | 3057                                          | 4            | Very High Hazard     |
| 28 | Semampir     | 12.2                            | 1227                                          | 4            | Very High Hazard     |
| 29 | Blaru        | 11.16                           | 2672                                          | 4            | Very High Hazard     |
| 30 | Kedungmulyo  | 14.25                           | 19                                            | 4            | Very High Hazard     |
| 31 | Mustokoharjo | 12.92                           | 1665                                          | 4            | Very High Hazard     |
| 32 | Gajahmati    | 12.66                           | 328                                           | 4            | Very High Hazard     |
| 33 | Panjunan     | 11.99                           | 3294                                          | 4            | Very High Hazard     |
| 34 | Banjarsari   | 13.82                           | 1169                                          | 4            | Very High Hazard     |
| 35 | Langenharjo  | 13.05                           | 1603                                          | 4            | Very High Hazard     |
| 36 | Babalan      | 13.77                           | 81                                            | 4            | Very High Hazard     |
| 37 | Tanjang      | 13.67                           | 103                                           | 4            | Very High Hazard     |
From Table 4, it shows that the classification of the flood hazard level from the simulation scenario of the collapse of the Gembong Dam due to overtopping in the affected area states that all villages are at the 4th hazard level, which means 37 affected villages are exposed to a very high risk of danger. This is because the majority of the population of each village is more than 1000 people, thus affecting the level of danger to the number of people who are at risk.

4. Conclusion
From the analysis that has been done in the previous discussion then obtained several conclusions as follows:

1. The magnitude of the Probability Maximum Precipitation (PMP) for the Gembong Reservoir Catchment area of 12.02 km$^2$ is 944.75 mm. Meanwhile, the Probable Maximum Flood (PMF) amount is 780.967 m$^3$/s with a peak time at the 3rd hour.

2. Characteristics of flooding that occurred from the Gembong Dam break scenario using the Zhong Xing Program were 37 affected villages. The fastest flood arrival time was 1 hour, and the longest was 7 hours. The fastest flood receding time is 3 hours, while the longest flood peak time is 96 hours. The maximum flood depth occurred in Wonosekar Village as high as 5.129 m and the maximum flood speed/velocity that occurred was 13.120 m/s.

3. In all scenarios of dam break (top piping of flood water level, middle piping of flood water level, bottom piping of flood water level, and overtopping) obtained a flood inundation map with a minimum area of 53.164 km$^2$ which occurred due to the scenario of the break of the Top Piping and a maximum inundation area of 54.682 km$^2$ that occurred due to the Overtopping scenario. There are 37 affected villages based on mapping of flood inundation in the affected area due to the Gembong Dam break scenario obtained from the Zhong XingHY21 software and has been overlaid on the administrative map of Pati Regency.
4. Classification of the flood hazard level from the simulation of the Gembong Dam break scenario due to overtopping in the affected area states that all villages are at the 4th hazard level, which means 37 affected villages with a total of 80,819 inhabitants are exposed to the risk of very high hazard. It is because the majority of the population of each village is more than 1000 people, thus affecting the level of danger to the number of residents who are at risk.

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