Flood inundation numerical modelling due to dam break of Way Sekampung Dam

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Abstract. Dam construction holds a major disaster risk in when the dam is failure. The occurrence of dam breach can make water reservoir in the dam flow to the downstream at high speed, so it can cause infrastructure damage and the worst is, victim. This study analyses the extent of flooding in the resulting dam break with piping failure mode. The simulation was conducted using HEC-RAS 5.07, with input data consist of Digital Elevation Model (DEM), precipitation data, and dam’s technical specifications. The research object is Way Sekampung Dam. The result of simulation show that after dam breach water flowing to the downstream with depth is 48.6 m and flood inundation area in Pringsewu District is 43,17 km².

1. Introduction

Dam construction is a technology to retain water on land. It has purposes for water supply, irrigation, hydroelectric power, etc. The most dam construction type in Indonesia is embankment dam. This is chosen because it can be built on almost all soil conditions. The construction material for dam body can be taken from the soil around it (Sosrodarsono & Takeda, 1977). The embankment dam weakness is being not able to hold water runoff and may cause a landslide on the downstream slope that can make the dam destroyed.

When the dam construction has been operating, it can cause serious disasters. The large volume water in reservoir will flow at high speed, so it can destroy the buildings in the downstream. Various studies for the dam breach have been conducted to minimize the risk occurrence (Xiong, 2011). Many causes that triggered the failure of the dam also became an interesting study to be examined and simulated (Gourbesville, Cunge, Caignaert, 2012). Ministry of Public Works and Housing (PUPR) as an administrator agency issued Ministerial Regulation No. 27/PRT/M/2015 (2015) regarding Dam. The state regulation for dam operation has been made with an emergency plan document that contains study about dam breach.

The object of this study takes place in Way Sekampung Dam located in Pringsewu, Lampung. Way Sekampung Dam location is about 14 km from the capital of Pringsewu regency, which is a populated area. The study about flood inundation is important to give a location estimation that can possibly be affected by a dam breach. The purpose of this study is to simulate flood inundation due to a dam breach in Way Sekampung Dam using numerical model.
2. Literature review

2.1. Breach parameter

Flood wave prediction caused by a dam breach has high uncertainty (Dewals, et.al. 2014) due to limited information about a dam breach process, time and trigger. Froehlich (2008) collected 74 dam breach cases in embankment dam to get formulation of breach dimension, consisting of average width \( \bar{B} \), side slope ratio \( z \), height \( H_b \), water volume above breach bottom \( V_w \), and formation time of the breach \( t_f \). \( K_0 \) is constant of overtopping failure (1,3) and piping failure (1).

\[
\bar{B} = 0.27K_0V_w^{0.32}H_b^{0.04} \tag{1}
\]

\[
t_f = 63.2 \sqrt{\frac{\nu_0}{g\bar{h}^2}} \tag{2}
\]

\[
B_t = \bar{B} + zH_b \tag{3}
\]

\[
B_t = \bar{B} - zH_b \tag{4}
\]

2.2. HER-RAS for dam break study

HEC-RAS can be used to simulate a dam breach and analyse flood hydrograph by using Saint Venant, Diffusion Wave, or pool routing method. Brunner (2014) stated that the most accurate model technic to capture height and overflow of long narrow reservoir pond is full dynamic wave (unsteady flow). Unsteady flow will be more accurate for with and without breach scenarios. In this method, cross section needs to be created along the reservoir or to create a reservoir pond as a two-dimensional flow. Furthermore, the dam is modeled with the inline structure option.

There are two dam breach failure modes that can be simulated by HEC-RAS: piping and overtopping failure modes. Information that is required for dam breach simulation is area location, failure mode, shape, time, trigger mechanism, weir and piping coefficient, failure location, failure mode (Bruner, 2014).

HEC-RAS has been used for the number of dam breach research such as Ikrom & Wardhna (2020), Yi Xiong (2011). The results of these studies are the determination of high, velocity, and time lag for three scenarios of a dam breach.

3. Research methods

3.1. Study area

Way Sekampung dam is located in Bumi Ratu village, at the right side of the river is Banjero village and at the left side of the river is Pringsewu, Lampung province. The inflow of Way Sekampung dam comes from Way Sekampung River and the discharge of Batutegi Dam. The type of the dam is a rockfill dam. Volume capacity of this dam is 68 million m\(^3\) with effective volume is 33.46 million m\(^3\). This dam has an overflow spillway and a two-gate spillway. The technical data of Way Sekampung dam are shown as follows:

- **Catchment area**: 346 km\(^2\)
- **Max Water Level**: +130
- **Normal Water Level**: +124
- **Height / Length**: 55 m / 362 m
- **Width**: 10 m
- **Elevation of overflow spillway**: +124
- **Elevation of gate spillway**: +116
3.2. Hydrology analysis
Hydrology analysis has purpose to show the water debit that would come to dam in PMF condition. PMF calculation for Way Sekampung Dam is carried out in 3 stages: (1) hydrograph PMF from Way Sekampung Dam watershed; (2) hydrograph from reservoir routing when PMF outflow occurs; (3) calculation of the superposition of both of the hydrographs.

The PMF from the Sekampung Way Watershed is calculated using the Hearsfield formulation. The unit hydrograph is calculated using nakayasu unit hydrograph. Reservoir routing data of Batutegi Dam are obtained from PT. Indra Karya Wilayah 1 (2016). Then, the superposition from the hydrograph is shown in Figure 2.

3.3. Spatial analysis
Spatial analysis is conducted to get contour information for research location, and can be used to simulate basic geometry. Digital Elevation Model (DEM) from DEMNAS with a scale of 1:50.000 is used for this process (http://tides.big.go.id/DEMNAS/DEMNAS.php).
3.4. Model setup
Modeling used HEC-RAS 5.07 of full dynamic wave. Cross section is created along the upstream side, while for the downstream area, it is created with a combination of 1D and 2D. Model combination is made with cross-section connection between 2D area with a lateral structure. The 2D area location was chosen in low elevation area. Hydrograph flow with PMF debit is used for unsteady flow boundary condition in the upstream river, while normal depth is used for the downstream river. Water gate boundary used gate with controlled elevation.

3.5. Boundary condition
Boundary condition of this research involves:
1. Gate spillway does not work;
2. The simulation does not cover lateral inflow in the downstream area;
3. Only captured flooded areas in Pringsewu district;

3.6. Breach Parameter
The dam breach parameter would follow equation made by Froehlich (2008), and failure mode is caused by piping in the crest dam in elevations +120. Inline structure breach is filled with formula (1), (2), (3), (4), with results as shown in Table 1.

| Parameter | Value     |
|-----------|-----------|
| $B$       | 100.14 m  |
| $t_f$     | 1.25 hour |
| $B_t$     | 126.04    |
| $B_b$     | 74.24     |
| $k$       | 1         |
| $z$       | 0.7       |

The dimensions of the dam breach calculated in Table 1 cannot be directly entered in HEC-RAS because the dimensions of dam breach cause scour on the valley topography. Meanwhile, this formulation doesn’t representative with these conditions. Therefore, we need to adjust the dam breach dimensions as can be seen in Figure 3.

4. Result and discussion
Simulation results show that HEC-RAS could simulate the dam breach with the conducted settings. Dam condition before and after dam breach are shown in Figure 4.
Figure 4. Comparison of Way Sekampung dam before and after the breach

Figure 5. Present situation of inundation area from RAS-mapper. The closest location with high population is Pringsewu district. There are 5 districts affected by the flooding namely Ambarawa, Pringsewu, Gadingrejo, Sukoharjo and Banyumas. Table 2 shown the total inundated area at Pringsewu District is 43.14 km² with Gadingrejo becomes the area with the most extensive flood inundation.

Table 2. Flood Inundation Area In Pringsewu District

| Sub District | Area (km²) |
|--------------|------------|
| Ambarawa     | 7.48       |
| Pringsewu    | 14.11      |
| Gadingrejo   | 19.83      |
| Sukoharjo    | 0.63       |
| Banyumas     | 1.09       |
| **Total**    | **43.14**  |

Figure 5. Pringsewu Regency Flood Inundation Map

To see the danger of flood disaster, the hazard area classification is based on inundation height. The categories are based on the Wirustyastuko and Nugroho (2013) which divided flood inundation into 3 categories. However, the average inundation height in Pringsewu district exceeds 2 m and the highest inundation is 49 m, therefore the addition of the classification is made to 5 categories (Table 3).

Table 3. Depth Classification

| Category | Depth (m) | Area (km²) |
|----------|-----------|------------|
| 1        | 0 – 2     | 7.34       |
| 2        | 2 – 5     | 12.75      |
| 3        | 5 – 10    | 17.26      |
| 4        | 10 – 15   | 4.66       |
| 5        | 20 – 50   | 1.13       |
| **Total**| **43.14** |            |
5. Conclusion

- The inundation area that occurred due to the Way Sekampung dam breach caused a flood inundation of 43.17 km$^2$ in Pringsewu district.
- The largest inundation area is in Gadingrejo district with an area of 19.83 km$^2$.
- Maximum depth is 49m, with the largest area in category 3 (5 – 10 km$^2$) of 17.26 km$^2$.

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