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ASSESSMENT OF FLOOD PROPAGATION DUE TO SEVERAL DAMS BREAK IN BANTEN PROVINCE

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ABSTRACT: River Basin Organization of Cidanau-Ciujung-Cidurian (RBOC3) is a water authority in Banten Province that has the planning of six rockfill dams in development planning, i.e Karian, Pasir Kopo, Tanjung, Cilawang, Sindang Heula, and Cidanau Dam. Regarding to the emergency response plan, it is necessary to have an inundated area estimation due to a dam break. The objective of this study is to develop a flood hazard map based on dam break analysis in selected dams in Banten Province so that the flood situation can be understood. HEC-RAS software was utilized to simulate the two-dimensional flood propagation. The result shows that the total of inundation due to all dam failure is around 152 km^2. The effect of this Karian Dam submerges 46% of the total area and volume of inundation from six rockfill dam failure. Also, Sindang Heula Dam and Cilawang Dam were considered as the second and third biggest impact on flood volume compared to the others dam break. This study can be used as the initial flood hazard map information in order to reduce flood damage in the future period under the massive construction. Furthermore, the result of this simulation could be applied to emergency response plans as the requirement of dam operation.

Keywords: Dam break, Emergency response plan, Flood hazard map, HEC-RAS simulation, Inundation area,

1. INTRODUCTION

Banten is one of the provinces located in Java, Indonesia. To stimulate the economic pace, this province has a responsibility to supply water to industries and farms. Moreover, it is one of the cities that supports Indonesia's capital city with clean water. River Basin Organization of Cidanau-Ciujung-Cidurian (RBOC3) is a water authority in Banten. Due to water management, the RBOC3 has planned several dam constructions in this region. At this time, Banten has developed the planning of six rockfill dams, i.e Karian, Pasir Kopo, Tanjung, Cilawang, Sindang Heula, and Cidanau dams. Several dams, namely the Karian and Sindang Heula dams are already in the final completion stage.

Hazard possibility could happen whether dam failure takes place. The enormous amount of water would inundate a downstream area of the dam and make huge loss to the construction, economy, and casualties. In 2009, a dam failure happened in Situ Gintung dam, South Tanggerang, Indonesia. The Situ Gintung dam failed due to overflow that lasted a very long time [1]. At that time, the Situ Gintung dam-break casualties were reportedly reach more than hundreds of people. Another case of dam-break in Indonesia is happened at the Way Ela Dam which is located in Leihitu District, Ambon Island. According to Badan Nasional Penanggulangan Bencana (BNPB) which is responsible for disaster management in Indonesia, extreme rainfall caused the failure of this natural dam. It was reported that the disaster destroyed more than 350 housing units and other public facilities.

From the historical event, the impact of dam failure needs to be evaluated to reduce the flood damage losses. The dam break analysis is an approach method to calculate flood propagation [2][3]. Also, there are many dam break simulations software such as HEC-RAS, FLDWAF, and DAMBREAK. Gee et al. [4] compared FLDAW with USACE Hydrologic Engineering Center's River Analysis System (HEC-RAS) model in aspect to flood routing. They found that both simulations produce comparable computational results for similar breach parameters, cross-section properties, and boundary conditions. Besides, those models are still a complicated and comprehensive process, it means that the actual failure mechanics are not well understood [5]. Changzhi et al. [6] simulated a one-dimensional dam break analysis at Muyu Reservoir Dam, China. They concluded that the usage of the dike system in the simulation was not significant to the results. Another study was conducted by

Sharma et al. [7] for a one-dimensional flood propagation model in Ajwa Dam, India. They emphasized that the flood water depth in the model with the dam break analysis numerically was higher compared to without dam break event process Yakti et al. [8] simulated a two-dimensional dam break analysis in HEC-RAS for Way Ela Dam, Ambon Island. The result corresponded well with the observed spatial data map. All of the study above indicate that the study of dam break failure has been carried out with various method. Then, each of model resulted in convergence and made the dam break model much better than before.

There are many studies that have been conducted to develop the dam construction in Banten. However, there is no study to show any information related to the flood potential map which is important for hazard assessment [9][10] to the constructed dams. The main objective of this research is to conduct a flood hazard map due to dam break analysis in selected dams in Banten Province. HEC-RAS software was utilized to simulate the two-dimensional flood propagation. This study analyzes six rockfill dams at each location. Also, we developed the flood hazard map in order to understand the flood situation because of the dam break process.

2. DATA AND DAM BREAK MODELLING

2.1 Study Area

Geographically, the study area is located between 5°7'50" S - 7°1'11" S and 105°1'11" E - 106°7'12" E. Fig. 1 shows the administrative boundary of the study area.

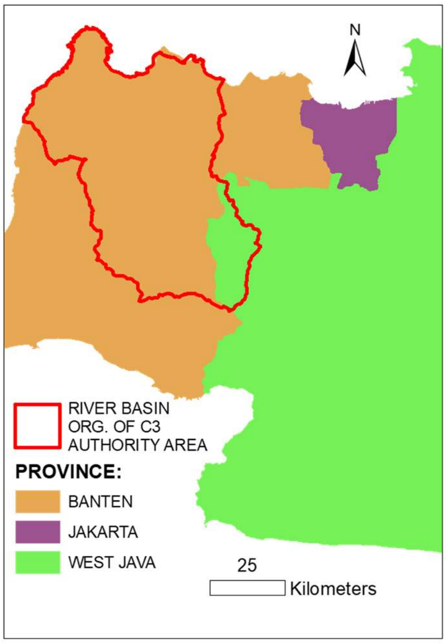

Fig.1 Location of study area

This study simulated six rockfill dams in the Province of Banten, i.e Karian, Pasir Kopo, Tanjung, Cilawang, Sindang Heula, and Cidanau Dam. The dams are in the Cidanau-Ciujung-Cidurian River Area. The simulated parts of the river area are Cidanau, Cibanten, Cidurian, and Ciujung River Basin. The catchment area with each dam location is presented in Table 1 and Fig. 2.

Table 1 Catchment area

No.	Dam	River Basin	Catchment Area (km^2)
1	Karian	Ciujung	2002
2	Pasir Kopo		
3	Tanjung	Cidurian	733
4	Cilawang		
5	Cidanau	Cidanau	226
6	Sindang Heula	Cibanten	257

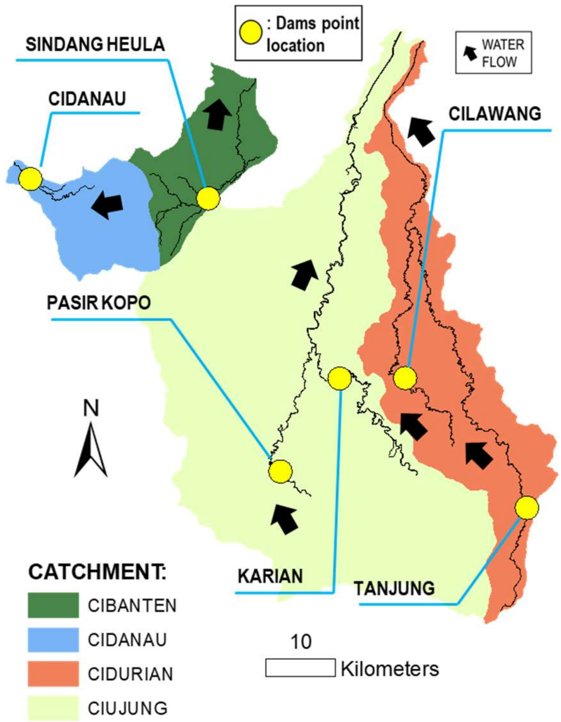

Fig.2 River basin area and dam's location

2.2 Hydrology Datasets

This simulation utilized inflow based on Probable Maximum Flood as in Fig. 3. This condition was determined to avoid overtopping failure that is very dangerous due to the rapid and large sudden damage. The hydrograph was obtained from the previous study except for Pasir Kopo Dam. Hence, the Pasir Kopo Dam's inflow was calculated by comparing the catchment area and river length to other dams. In this case, Karian sub-basin was determined as the baseline to be compared with the Pasir Kopo sub-basin.

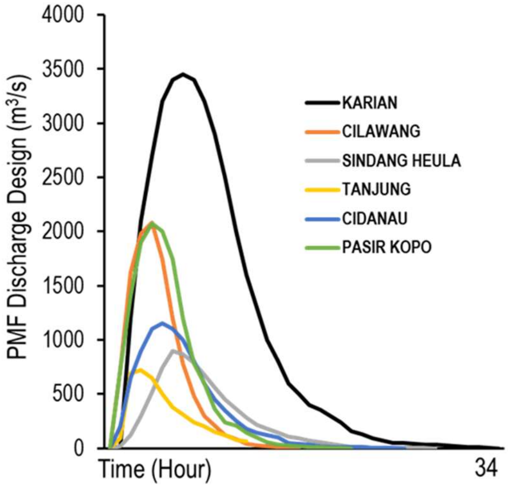

Fig.3 Probable maximum flood hydrograph

2.3 Topography Data

In this model, the Digital Elevation Model was obtainable from the Shuttle Radar Topography Mission (SRTM). SRTM is provided by the US Geological Survey (USGS) from the mission between the National Imagery and Mapping Agency (NIMA) and the National Aeronautics and Space Administration (NASA). This data was an open-source data from The USGS Earth Explorer website. For the accuracy, the vertical direction is 16 m for a 90% confidence level [11]. Jarvis,A. *et al.* have experimented with SRTM in tropic condition and it resulted that the SRTM 3 Arc second DEMs perform well on hydrological modelling in the margin usability. Therefore, in this study, the simulation utilized 1 arc second or about 30 m DEM from SRTM.

2.4. Dam Break Analysis

Dam break analysis calculated the effect of dam failure on the reservoir and surrounding areas. There are several complete causes of dam failure based on the USACE Hydrologic Engineering Center (HEC) Research document, i.e., earthquake, landslide, extreme storm, piping, equipment malfunction, structure damage, foundation failure, and sabotage. Nevertheless, the main modes of dam failure are identified as piping, foundation defect, or overtopping. According to Costa [12], thirty-four of dam failure is caused by overtopping. This makes overtopping as the major cause of dam failure for all type of dams. Besides, overtopping happened very fast with large affected area compared with other kind of dam failure types. The maintenance or refinement will not possible to carried out because the sudden disaster. Because of that, this study emphasized to simulate overtopping scenarios to all of the dams.

In general, dam failure begins with breach formation in the dam structure. The dam breach occurs from the force that penetrates through dam structure. The breach equation estimates that the breach was developed starting from the dam peak and expand to the breach's bottom. There are various equations to predict dam breach parameters based on historical studies of dam failure. Wahl [13] have summarized regression equations for breach size and failure time. Among all of the equations, Froehlich [14] gives the best prediction performance in uncertainty conditions based on Wahl [15]. Therefore, this study determined breach parameters using Froehlich's regression equation as simplification as shown in Eq. (1) and Eq. (2).

$$B_{ave} = 0.1803\ K_0\ V_w^{0.32}\ h_b^{0.19} \tag{1}$$

$$t_f = 0.00254\ V_w^{0.53}\ h_b^{-0.90} \tag{2}$$

2.5 Land Cover

In this study, the land cover is used to define roughness in study area. The area was covered by forest in the upstream region, the n manning's value is 0.3. However, the area was covered by urban in the downstream region, the n manning's value is distributed from 0.3-0.6.

2.6 Flood Propagation Model

HEC-RAS v.5.0.7 is the software that modeled the two-dimensional propagation. Based on the HEC-RAS 5.0 Reference Manual, the governing equation for the flow rate equation in this model was mass conservation Eq. (3). For unsteady flow, momentum conservation is included in the governing equation in this model in x direction, shown in Eq. (4), and y diretion shown in Eq. (5).

$$\frac{\partial H}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} + q = 0 \tag{3}$$

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -g\frac{\partial H}{\partial x} + v_t\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - c_f u + f_v \tag{4}$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial H}{\partial y} + v_t\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - c_f u + f_u \tag{5}$$

where t is time, q is the source/sink flux term, u and v are the velocity components in x- and y directions respectively, g is the gravitational acceleration, vt is the horizontal eddy viscosity coefficient, cf is he bottom friction coefficient, R is the hydraulic radius, and f is the Coriolis parameter.

2.7 Maximum Reservoir Capacity

The maximum reservoir capacity was found from the DEM Data as can be seen in Fig. 4. The inundated area at each dams were calculated in the volume and the inundation area of the reservoir as in Table 2. Please be noted that, this condition was the maximum capacity of the reservoir before the dam fail. Karian Dam has the largest reservoir among all of the dams. The second-largest volume and inundation areas were Tanjung and Pasir Kopo Dam respectively.

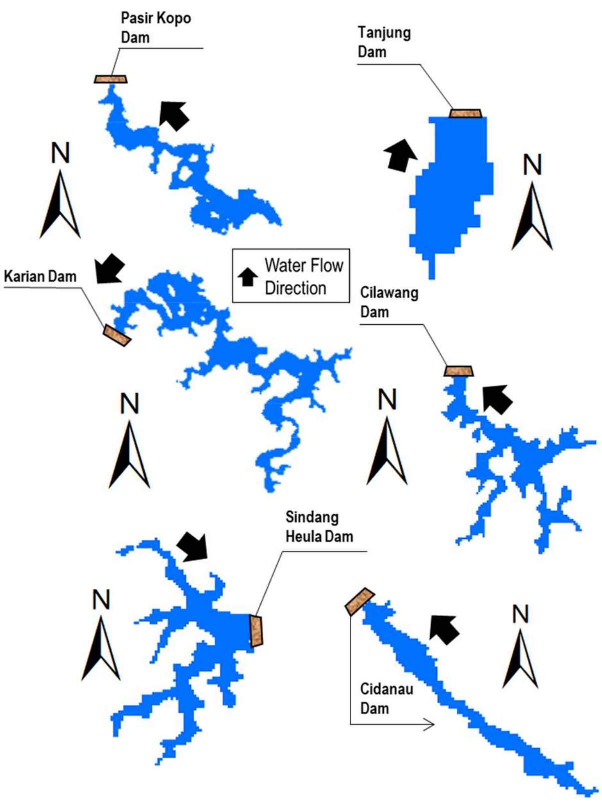

Fig.4 Reservoir inundation

Table 2 Reservoir capacity

No.	Dam	Reservoir Capacity	
		Volume ($10^6.m^3$)	Inundation Area (km^2)
1	Karian	314.71	15.93
2	Cilawang	26.38	3.7
3	Tanjung	169.00	4.24
4	Pasir Kopo	130.80	8.5
5	Cidanau	21.00	1.3
6	Sindang Heula	9.26	1.05

2.8 Flood Mechanism

There was an assumption process that the rivers were in the normal flow before the dams fail. It means that the rivers are already filled by water at the normal water level. This condition was affected by the DEM that read the elevation of the river as the ordinary water level. After the dam broke down, the additional water flow from the reservoir increased the river flow abruptly. Figure 5 shows the mechanism of flow enlargement in flood conditions. Part A is the flow when dam failure affects the river flow. The total flow in the river increased until a certain time and decreased until the dam relatively empty. From the part B, the water level back to normal because there is no additional flow from the dam.

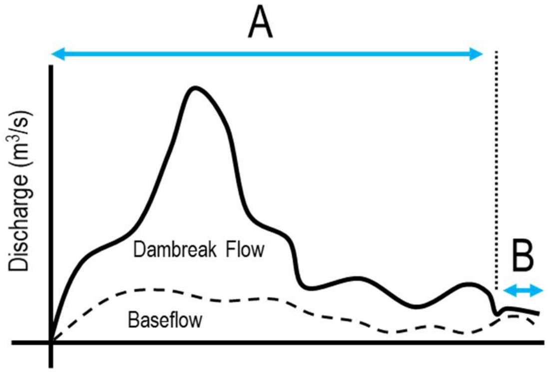

Fig. 5 Flood mechanism

3. RESULTS AND DISCUSSIONS

3.1 Simulation Process

The input data sets in dam break analysis are five data types, such as hydrology data, topography data, dam dimensions, breach parameters, and land cover. In this simulation, the two-dimensional hydraulic model was built by combined the topography data, land cover, and dam dimensions. Then, the breach parameters shown in Table 3 were defined to the studied dam. The hydrology data, as a discharge hydrograph, was simulated to this model as the independent variable.

Table 3 Breach parameters

Dam	Dam Height (m)	Breach Bottom Width (m)	Breach Transformation Time (hr)	Breach Slope (xH:1V)
Karian	52.5	172.19	1.84	1.4
Pasir Kopo	65.0	126.44	1.16	1.4
Tanjung	55.0	155.12	1.58	1.4
Cilawang	25.0	88.95	1.46	1.4
Cidanau	50.0	53.19	0.62	1.4
Sindang Heula	43.5	26.75	0.42	1.4

At the beginning of the simulation, the discharge was streamed on the upstream of the dam. The reservoir was filled until a certain level and reached its maximum capacity (Sec. 2.6). At the same moment, the water elevation exceeded the dam elevation and made the discharge come out from the top of the dam. This started the breaching process at the peak of the structure called overtopping. Then, the water eroded the dam until the dam breach fully created.

The flood inundation in the downstream was caused only by with the discharge that propagated from the dam. In other words, another hydrological input such as precipitation was not calculated in the downstream. Hence, the only hydrological source in this simulation was the discharge generated in the upstream of the dam due to dam failure. This boundary of condition could make the simulation result may be different than the actual disaster that can be happened. Nevertheless, the error might be very slightly because of large amount of water from PMF discharge.

3.2 Flood Inundation Map

From the simulation, there are different results from each dam for the volume and the volume and area of flood inundation situation as can be seen in Fig. 6. The total of inundation whether all of the dam fails is 152 km^2. This condition is rarely happened or even not possible to happen at all. According to the authority area of RBOC3, the flood may overwhelm 4% of the total area which is 4,144 km^2.

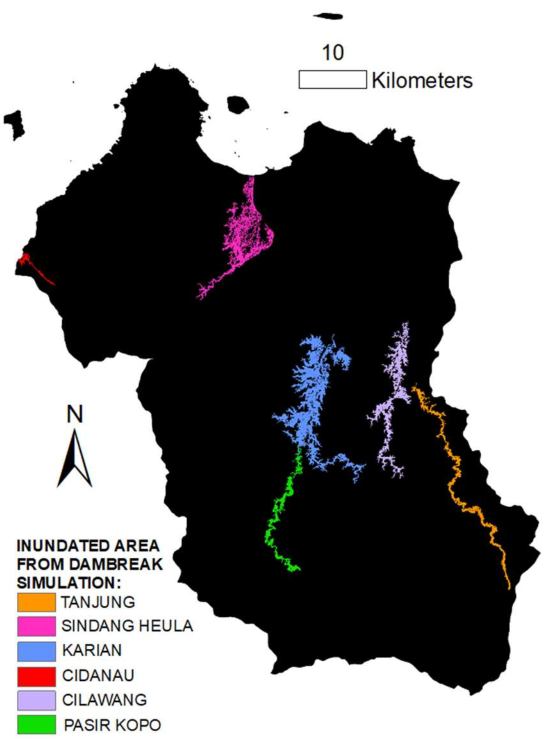

Fig.6. Flood inundation map

Table 4 showed the volume and area of inundated because of the dam break situation at each dam. Please be noted that the maximum flood volume and area were computed by maximum inundation depth and area derived from the simulation results in this study at each dam break situation. In this Table 4, the water inundated situation in the reservoir was extracted in order to obtain the original flood inundation situation in the downstream area at each dam failed process. From the result, it can be seen that the impact of Karian Dam failure to the downstream was greatest compare to the others dam failure shown in Fig. 6.

Table 4 Simulation results

No.	Dam	Simulation Result	
		Volume ($10^6.m^3$)	Inundation Area (km^2)
1	Karian	136.33	62.29
2	Pasir Kopo	41.72	13.39
3	Tanjung	18.39	18.29
4	Cilawang	43.14	25.89
5	Sindang Heula	26.61	31.37
6	Cidanau	31.78	1.62

The effect of this Karian Dam submerges 46% of the total area and volume of inundation from six rockfill dam failure. Also, Sindang Heula Dam and Cilawang Dam were considered as the second and third biggest impact on flood volume compared to the others dam break failed. The flood volume at the downstream area of Sindang Heula Dam and Cilawang Dam are 8,93% and 14,48% of the total flood volume of those all dams break failed, respectively.

The same as the flood inundation evaluation, we evaluate the impact on the inundated area at each dam break failed. As already mentioned, that the Karian Dam is the biggest impact on flooded area because of its dam break. There are two dams with the second biggest impact on flooded simulated area, those are Pasir Kopo and Cilawang Dam. It can be found from Table 4 that there are no significant differences between those two dams in the flooded area. Please be noted that the Cilawang Dam was considered with the high potential flood inundation volume under the dam break failed process numerically. As the result of analysis that Cilawang Dam should be selected as the second highest potential dam because the impact of flood is not only biggest in flood inundation volume but also flood inundated area. Also, Cidanau Dam was considered as the third biggest impact on flood area compared to the others dam break failed.

It should be emphasized that we developed the rank classification of flood hazard on volume and area in order to understand the mechanism of flood impact at each dam break failed separately. This study can be used as the initial flood hazard map information in order to reduce flood damage at the future period under the massive construction.

4. CONCLUSIONS

In this study, the simulations applied the dam break model into six dams in Banten, i.e., Karian, Pasir Kopo, Tanjung, Cilawang, Sindang Heula, and Cidanau Dam. The inflow that utilized in this model was Probable Maximum Flood (PMF). The dam failure from Karian Dam had the largest effect among all of the dams. It is proven by the capacity and the inundation area after the dam failure.

The result of this simulation could be applied to the emergency response plan as the requirement of dam operation. Nevertheless, economic assessment is needed to measure exact loss due to dam failure. Therefore, the prioritized treatment plan could be arranged for RBOC3.

5. ACKNOWLEDGMENTS

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