Dam break analysis of Situ Gintung Dam collapse reconstruction

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Abstract. On March, 27th 2009 Situ Gintung dam collapsed. Situation Gintung dam failure has been analyzed based on the condition of watershed, reservoir, and embankment on March, 27 2009. Hydrological analysis and slope stability analysis are combined to analyze the major causes of Gintung collapse. Watershed analysis using ARC-GIS software, routing in reservoir using HEC-HMS model, and stability condition was studied using Geo-Slope. Input data, parameters, and model assumptions are very important to get the right results. Hydrological analysis results show that rain occurred on March 26, 2009 with a rainfall intensity of 111 mm/day was only classified as rainfall with a return period of 5 years. Reservoir routing show that water level elevation on March, 27 2009 was only 70 cm above the spillway crest or 1.3 m below the embankment crest with a peak flow of 36.2 m³/s, so it didn’t cause overtopping on the embankment. Slope stability analysis results show that the factor of safety of 1.19 < 1.5 (standard), it show that there was the weakening of the dam, such as scouring, erosion, and cracks. It can be concluded that the main factor of the collapsed was caused by scouring and cracks.

1. General Background
The Situ Gintung Dam collapsed on March 27, 2009. Based on an assessment conducted by the Ministry of Public Works (2009), it is suspected that the main causes of collapse were internal erosion (channeling piping), and scouring. On March 26, 2009 the intensity of rainfall recorded at the Ciputat rain station was 111 mm/day. The causes of dam break in this study were analyzed based on two aspects, that is hydrology and slope stability. The hydrological aspects were analyzed by the HEC-HMS program, by simulating flood runoff hydrographs. While the slope stability is analyzed by modeling in the Geo-Slope program. In this research, a hydrological analysis and stability analysis of the Gintung Dam slope will be combined [1-5].

2. Literature Study
2.1. Level Pool Routing
Level pool routing is the easiest method of tracking. The flow velocity in a reservoir is very small, and the water level in the reservoir is assumed to be horizontal. Pool level routing is a procedure for calculating outflow hydrographs from a reservoir or reservoir with a horizontal water level [6-10].

\[
\frac{(2S_j + 1 + Q_j + 1)}{\Delta t} = (I_j + I_{j+1}) + \left(\frac{2S_j}{\Delta t} - Q_j\right)
\]
The above equation is a storage-outflow function that is used to develop the function of the relationship between elevation-storage and elevation-discharge (inflow).

2.2. Reservoir Modelling at Hec-HMS
The relationship between storage-outflow (elevation-storage-outflow) depends on the characteristics of the reservoir, outlet, and spillway. When the water overflow over the dike, it can be used in equation the spillway rating function:

\[ O = C \cdot L \cdot H^{1.5} \]  

(2)

Where:
- \( O \): Outflow (m³/s)
- \( C \): Dimensional discharge coefficient
- \( L \): Spillway width (m)
- \( H \): Total head (m)

2.3. Slope Stability
Landslide can occur when the slope balance is disturbed enough to overcome the shear stress of the soil. Factors affecting slope stability are ground shear strength, and seepage.

### Table 1. Factor of Safety Value

| Slope condition | Factor of safety recommendation |
|-----------------|---------------------------------|
| permanent       | 1.5                             |
| temporary       | 1.3                             |

3. Methodology of Study
This study performed on Situ Gintung Dam watershed which was analyzed using ARC-GIS referring to the DEM map and satellite imagery map. To obtain the Gintung dam watershed, a contour and high point analysis on the DEM map is input on Arc-GIS (Geographic Information Spatial). In this study the land use area used was 2009, to reconstruct the collapse of the Situ Gintung embankment on March 27, 2009. The land use map was obtained by digitizing. Land use maps were obtained by digitizing maps of satellite images using Arc-GIS.

Next, the rainfall analysis with the return period is compared with the intensity of the rain that occurred during the Gintung collapse on March 26, 2009. After analyzing the rainfall in the watershed, the rainfall intensity can be input into the HEC-HMS with the SCS-STORM method.

Hydrological modeling in this study using HEC-HMS. The results of the simulation produce a flood runoff hydrograph with inflows and outflows, due to the elevation-storage-discharge input in the reservoir. The results of hydrographs on hec-hms depend on the amount of discharge that flows over a specified period of time. In addition, the results of the simulation with HEC-HMS are peak elevation on March 27, 2009, when the Gintung dam collapsed.

Dam slope stability was analyzed using Geo-Slope/w software. Simulations performed are with two modeling scenarios namely Simulation of slope stability analysis with stable dam conditions and crack conditions on embankment bodies.

4. Results and Discussion
4.1. Delineation of Gintung Dam Watershed in 2009
Gintung Dam watershed delineation generated by software and tools on the ARC-GIS with DEM (Digital Elevation Model) map and the Ciliwung-Cisadane river map inputs. Below is the result of a
watershed boundary that has been corrected. Below is the result of a watershed boundary that has been corrected.

![Figure 1. Situ Gintung Dam Watershed Delineation](image)

Based on the picture above, the Gintung dam watershed is divided into 4 sub-watershed. Subdivision is based on the inlet point at the Gintung Dam. Here is a Gintung dam watershed schematic.

![Figure 2. Gintung Watershed Schematic](image)

### 4.2. Watershed Topographic Condition

Based on the results of the ARC-GIS analysis, the Gintung reservoir area in 2009 was 25.4 Ha. Whereas based on BBWS Ciliwung-Cisadane data, the initial area of the Gintung Dam built by the Netherlands was 31 hectares. So that the Gintung reservoir area has decreased by 18%. The results of the GIS analysis show the total area of the Gintung Dam watershed, is 5.35 km². The following is a conclusion table for the results of an analysis of the topography of the Gintung Dam watershed in 2009.

| Sub-watershed | Area (km²) | High Point (m) | Low Point (m) | Height Difference (m) | L (m) | Slope (%) |
|---------------|------------|----------------|---------------|-----------------------|-------|-----------|
| 1             | 3.24       | 75             | 54            | 21                    | 5116  | 0.4       |
| 2             | 1.16       | 59             | 44            | 15                    | 1527  | 0.9       |
| 3             | 0.16       | 52             | 45            | 7                     | 793   | 0.8       |
| 4             | 0.78       | 47             | 41            | 6                     | 416   | 1.4       |

### 4.3. Land Use Condition and CN Weighted

Gintung Dam watershed land use areas in 2009 are grouped into residential (1.4m²), commercial/business (0.04 m²), open space (0.04 m²), open space (2.8 m²), Pavement (0.3 m²), roadway
(0.6 m²), water (0.009 m²), and Gintung Reservoir (0.25 m²). Based on the land use area and the CN coefficient of each land cover, the CN value is weighted in the Gintung Dam watershed of 75. The weighted CN value for sub-watershed 1, 2, 3, and 4 is 78, 81, 81, 51.

4.4. Rainfall Analysis
According to the Situ Gintung Disaster Expert Assessment Team of the Department of Public Works, on March 26, 2009 from 1:00 to 19:30 with a break of 1.5 hours at 14:30-16:00 there was rain with a very heavy intensity category according to BMKG, which is recorded at the Ciputat rain post with an intensity of 111 mm/day. Determination of average regional rainfall aims to take the average value of the nearest rain station in the Gintung Dam watershed area. The rain stations used in this study were the South Tangerang rain station (2.38 km²), the FTUI rain station (1.3 km²), and the Depok rain station (1.6 km²). Next, calculate design rainfall for several return periods (years). Analysis of the design rainfall uses the method of the distribution of Gumbel and log Pearson type III. Distribution suitability test on Gumbel and log Pearson type III using chi square test and Kolmogorov Smirnov test. Recap the results of the design rainfall data for each return period using the 3 rain stations nearest to the Gintung dam watershed as follows.

| Table 3. Design Rainfall |
|--------------------------|
| Return Period (Year) | R24 (mm) |
| 2 | 109 |
| 5 | 140 |
| 10 | 166 |
| 20 | 199 |
| 25 | 206 |
| 50 | 241 |
| 100 | 281 |

4.5. Hec-HMS Simulation Results
Routing in reservoir starts when the reservoir conditions are full at +98m elevation with a storage volume of 2,542,000 m³. With a watershed area of 5.3 km², reservoir area within the watershed of 25.42 ha, and also rain input on March 26, 2009 of 111 mm/day, the simulation results obtained using Hec-HMS is the peak flood (inflow) is 36.2 m³/s with water level elevation at +98.7 m elevation and the outflow is 13 m³/s. From the simulation results, it is known that the water level in the reservoir is 0.7 m above the spillway elevation. Because the dam elevation is +100m and still has a design height of 1.3 m, there was no overtopping on the dam on March 27, 2009.

![Flood hydrograph March 27, 2009 in Situ Gintung](image.png)
From the results of a simulation experiment with hec-hms, only a return period of 2 years, 5 years, 10 years, 20 years, and 25 years was successfully run. This represents that the Gintung dam at the beginning of construction in 1933-2009 only fulfilled life time for a 25 year return period.

| Return Period (years) | R24 (mm) | Q-inflow (m3/s) |
|-----------------------|----------|-----------------|
| 2                     | 109      | 35.4            |
| 5                     | 140      | 49.1            |
| 10                    | 166      | 61.2            |
| 20                    | 199      | 77.2            |
| 25                    | 206      | 80.7            |
| 50                    | 241      | error           |
| 100                   | 281      | error           |

4.6. Analysis of Dam Slope Stability with Geo-Slope

The simulation results of the Geo-Slope program depend on input parameters. The parameters used are the geometry of the dam, modeling the soil material based on the parameter of soil shear strength, modeling pore water pressure, and determining the location of the slip surface.

a. Based on the results of the analysis using Geo-slope, factor of safety of the slope assuming the condition of the dike in stable conditions is 1.674.

b. The results of geo-slope analysis with the second assumption are that cracks in the embankment and spillway are considered to have occurred, so that some of the strength of the shear strength parameter is in the residual condition, this is due to saturated soil thereby reducing the stickiness (cohesion) of soil particles in the embankment. FS value 1.19 <1.5 (standard).
The simulation results were compared with the collapse report prepared by the Situ Gintung disaster expert assessment team of the public works department.

5. Conclusion
Based on the results of the hydrological analysis, it shows that the Situ Gintung watershed hydrological conditions also contributed to the collapse of the embankment, but not as a major factor, because the routing results on the reservoir on March 27, 2009 with the HEC-HMS program show a flood peak (inflow) of 36, 2 m³/s, which when compared with the 5 year return period discharge of 49.1 m³/s, the peak flooding during the collapse event did not exceed the 5 year return period. The results of the slope stability analysis show that the main cause of the embankment landslide is the result of weakening of the embankment soil, presumably caused by erosion and cracking of the left embankment with spillway, causing the flow in the reservoir to enter through the crack and make the soil conditions in the embankment so saturated that it experiences decrease in shear strength parameters due to loss of stickiness between soil particles. Based on the modelling assumptions, the FS value is only 1.19 <1.5 (standard FS value).

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