Evaluation of the Open Diversion Channel Capacity on Margatiga Dam Construction Project using 6D BIM Analysis

Nugraha\textsuperscript{1}, F D Hermawan\textsuperscript{2, *}, S Monica\textsuperscript{3}

Margatiga Dam Project Manager, PT. Waskita Karya (Persero) Tbk, Indonesia
\textsuperscript{2}Site Engineering and Standardization Manager, PT. Waskita Karya (Persero) Tbk, Indonesia
\textsuperscript{3}Site Engineering and Standardization Officer, PT. Waskita Karya (Persero) Tbk, Indonesia

*Corresponding author: fandy.dwi@waskita.co.id

Abstract. The Margatiga Dam is designed to combine a gravity concrete dam and rockfill with an upright core. In the Margatiga Dam Project, river diversion is carried out in 2 stages. Stage 1 through a trapezoidal open channel with discharge plan of Q10 years approximately 789.10 m\textsuperscript{3}/second and stage 2 with the diversion discharge of Q25 years approximately 976.90 m\textsuperscript{3}/second. During construction, the stage 1 diversion channel is built with a capacity that exceeds the planned design due to the very high water level fluctuations. Moreover, an evaluation is needed regarding the annual plan discharge that passes through stage 1. The Evaluation is based on data from the desk study and 6D BIM analysis. Based on the analysis, the water level is at elevation +19.50. The discharge through the diversion channel on this stage is 884.69 m\textsuperscript{3}/second; this discharge exceeds the planned discharge design for diversion channel stage 1 with an annual Q10 discharge of approximately 789.10 m\textsuperscript{3}/second.

keywords: 6D BIM analysis, dam construction, diversion channel

1. Introduction

The construction of Margatiga Dam is part of the utilization of the Way Sekampung river from upstream to downstream or known as Cascade dam (Figure 1). Margatiga Dam combines a gravity concrete dam and rockfill with an upright core [1]. A gravity concrete dam is located in a riverbed. Embankment dams with upright core are located in river floodplains on the right and left sides of the concrete gravity dam [2]. Before constructing an embankment dam, it is necessary to complete the complementary structures of the dam, either in the form of temporary buildings or permanent buildings [3]. The most important complementary buildings dam is diversion channels, access road, river embankment and others [4, 5]. The construction implementation plan is prepared in such a way as to obtain an effective and efficient implementation sequence [6].

In the Margatiga Dam Project, river diversion is carried out in 2 stages. Stage 1 through a trapezoidal open channel with discharge plan of Q10 years approximately 789.10 m\textsuperscript{3}/second. Stage 2, with the diversion discharge of Q25 years approximately 976.90 m\textsuperscript{3}/second, can be channeled to the operation gate, which also functions as a flood controller (Figure 2)[1].
Figure 1. Way Sekampung river system from upstream to downstream

Figure 2. Margatiga Dam project at normal condition

Figure 3. Documentation of flood happened at Margatiga Dam because discharge capacity exceeds the planned design
During construction, the stage 1 diversion channel is built with a capacity that exceeds the planned design due to fluctuations in the very high river water level (see Figure 3). The planning mistake's impact causes service providers to lose due to idle work and operational costs during flood [7]. This paper aims to evaluate the discharge capacity that passes through stage 1 that exceeds the planned design with data from the desk study and 6D BIM Analysis.

2. Material methods

2.1. Desk study
The diversion channel is designed to release flood discharge with a return period of 10 years (Stage 1). In the diversion channel analysis, the Manning formula calculates the wet cross-sectional area. The wet circumference of each water level elevation so that the amount of discharge for each water level elevation is obtained [8,9].

The equation used:

\[ Q = v \times A \]  
\[ v = \frac{1}{n} \times R^\frac{2}{3} \times L^\frac{1}{2} \]  
\[ R = \frac{A}{Q} \]

The general characteristics of the diversion channel according to the calculation results of river diversion are as follows (Figure 4, 5):

- Dodge Type: Trapezoidal open channel
- Diversion channel length: 500.00 meter
- Channel Width: 40.00 meter
- Channel Heigh: 5.00 meter
- Upstream Base Elevation of Diversion Channel: +14.00 meter
- Downstream Base Elevation of Diversion Channel: +13.50 meter
- Longitudinal slope: 0.001
- Water Level: +18.59 meter
- Discharge Plan of Q_{10} years: 789.10 m³/s
- Slope of the embankment: 1:1
- Embankment width: 3.00 meter

![Figure 4. Design contract drawings for Margatiga Dam diversion channel](image)
Figure 5. Graph of the Relationship between Elevation and Discharge of the Trapezoidal Trapezoid Dam of Margatiga

Table 1. Resumes of flood discharge for various return periods of Margatiga Dam

| Flood Plan (years) | Margatiga Dam |
|-------------------|---------------|
|                   | Max Inflow (m³/s) | Max Outflow (m³/s) | Max TMS (M) |
|                   | Clark | SCS | Clark | SCS | Clark | SCS |
| 2                 | 474.7 | 500.9 | 404.4 | 457.3 | 22.71 | 22.78 |
| 5                 | 675.2 | 656.0 | 587.6 | 610.0 | 22.91 | 22.93 |
| 10                | 815.8 | 789.1 | 709.4 | 731.5 | 23.03 | 23.05 |
| 15                | 1042.1 | 976.9 | 895.6 | 893.8 | 23.21 | 23.20 |
| 50                | 1216.9 | 1136.6 | 1040.8 | 1029.3 | 23.34 | 23.33 |
| 100               | 1443.7 | 1304.0 | 1228.4 | 1173.6 | 23.51 | 23.47 |
| 1000              | 1932.4 | 2005.3 | 1627.7 | 1814.2 | 23.81 | 23.94 |
| PMF               | 5002.5 | 5162.5 | 4399.6 | 4681.0 | 25.53 | 25.69 |

Based on the planning design (see Table 1), the diversion channel Stage 1 can release flood discharge with a return period of 10 years or approximately inflow 789.1 m³/s.

2.2. 6D BIM analysis

This analysis method will use numerical analysis calculation with the help of 6D BIM analysis and later will be compared with the manual theoretical calculation from the planning design (Figure 6) [10].

Figure 6. 6D BIM analysis flowchart
2.2.1. Data collection
At this stage, data collection is performed when the diversion channel construction has been completed, and the stage 1 diversion channel has been activated. The data required are as follows:
1. Diversion channel design data during construction
2. Drainage water level data during construction

2.2.2. Data processing and analysis. After all the necessary data is collected, the analysis can be performed. The analysis is performed by comparing the planned discharge through the stage 1 diversion channel to the actual discharge that has passed through the stage 1 diversion channel. The method of determining the actual discharge through the diversion channel stage 1 is used as an equation (1). To calculate the wet section using the highest elevation of the actual water level passed the evasion channel construction. After obtaining theoretical calculations, the next stage is the calculation test stage using the 6D BIM analysis numerical analysis [10].

3. Result and discussion
In this study, the authors have made observations on the water level of the diversion channel, and the highest water level of the diversion channel occurred in February 2021 (Table 2).

Table 2. Summary of water level elevation in the diversion channel on February 2021

| No | Date     | Water Level Elevation (meter) |
|----|----------|-------------------------------|
| 1  | 01/02/2021 | 17.15                         |
| 2  | 02/02/2021 | 17.50                         |
| 3  | 03/02/2021 | 17.80                         |
| 4  | 04/02/2021 | 18.30                         |
| 5  | 05/02/2021 | 18.60                         |
| 6  | 06/02/2021 | 19.50                         |
| 7  | 07/02/2021 | 18.90                         |
| 8  | 08/02/2021 | 17.67                         |
| 9  | 09/02/2021 | 17.78                         |
| 10 | 10/02/2021 | 17.90                         |
| 11 | 11/02/2021 | 17.98                         |
| 12 | 12/02/2021 | 16.70                         |
| 13 | 13/02/2021 | 17.05                         |
| 14 | 14/02/2021 | 16.88                         |
| 15 | 15/02/2021 | 16.25                         |
| 16 | 16/02/2021 | 17.08                         |
| 17 | 17/02/2021 | 18.10                         |
| 18 | 18/02/2021 | 18.35                         |
| 19 | 19/02/2021 | 17.50                         |
| 20 | 20/02/2021 | 16.60                         |
| 21 | 21/02/2021 | 15.70                         |
| 22 | 22/02/2021 | 15.45                         |
| 23 | 23/02/2021 | 15.45                         |
| 24 | 24/02/2021 | 15.40                         |
| 25 | 25/02/2021 | 16.10                         |
| 26 | 26/02/2021 | 16.00                         |
| 27 | 27/02/2021 | 16.80                         |
| 28 | 28/02/2021 | 16.30                         |
Based on observational data, the highest water level occurred on February 6, 2021, with an elevation of +19.50 (Figure 7). The technical data for the construction of the Stage 1 diversion channel is as follows (Figure 8):

- Channel Length : 480 meters
- Channel Base Upstream Elevation : +12.00
- Channel Base Downstream Elevation : +11.50
- Slope : 0.001

![Figure 7. Graph of water level elevation in diversion channel on February 2021](image)

![Figure 8. Shop drawing of diversion channel Stage 1 of Margatiga Dam Project](image)

- Manning's Value : 0.0245 (New straight, uniform, ramps and clean)
- Cross-sectional area : 299,887 m² (water level +19.50)
- Wet Cross : 66,747 m (water level +19.50)

**Table 3. Calculation of discharge at water level +19.50**

| A | P | R | V | Q |
|---|---|---|---|---|
| Cross-sectional area | Wet Cross | Hydraulic Radius | Speed (m/sec) | Discharge (m³/s) |
| m² | m | m | m/sec | |
| 299,887 | 66,747 | 4.49 | 3.59 | 1075.66 |
Figure 9. Documentation of Margatiga Dam Project diversion channel

From manual calculations, we can get the discharge at water level +19.50; the result is used to perform simulations using 6D BIM numerical analysis. Here are the calculation steps using numerical analysis on 6D BIM analysis (Figure 9, 10).

Figure 10. 3D Model BIM of Margatiga Dam Project
Based on the calculation data on February 6, 2021, with the water level at an elevation of +19.50, the discharge through the diversion channel is 1075.66 m³/s; this discharge exceeds the planned discharge used in the contract drawing with an annual Q10 discharge of 789.10 m³/s (Figure 11).

4. Conclusions
Based on the analysis and discussion, we can conclude that:
1. The maximum discharge that has ever passed through the stage 1 diversion channel is 1075.66 m³/sec and exceeded the planned discharge
2. The stage 1 diversion channel is safer if it is designed using a discharge with a return period of 25 years than using discharge with a return period of 10 years

Acknowledgments
Authors wishing to acknowledge assistance from colleagues and financial support from PT Waskita Karya (Persero) Tbk

References
[1] Lidya Susanti, Eddy Purwanto, Endro Prasetyo Wahono 2017 Perencanaan Pintu Pelimpah Bendungan Margatiga Kabupaten Lampung Timur Provinsi Lampung Jurnal Rekayasa Sipil dan Desain Vol 5 No 2
[2] Giacomo Sevieri, Anna De Falco, Marco Andreini, and Herman G. Matthies 2021 Hierarchical Bayesian framework for uncertainty reduction in the seismic fragility analysis of concrete gravity dams Engineering Structures Volume 246 113001 https://doi.org/10.1016/j.engstruct.2021.113001.
[3] Yan Zhang, Guo-Ping Xia 2008 Construction of high embankment dam material flow equilibrium system Expert Systems with Applications Volume 36 Issue 5 Pages 9175-9191. https://doi.org/10.1016/j.eswa.2008.12.025.
[4] Zhenwei Li, Xianli Xu, Chaohao Xu, Meixian Liu, Kelin Wang 2018 Dam construction impacts on multiscale characterization of sediment discharge in two typical karst watersheds of southwest China Journal of Hydrology Volume 558 Pages 42-54. https://doi.org/10.1016/j.jhydrol.2018.01.034.
[5] Dian Sisinggih, Sri Wahyuni & Pitojo Tri Juwono 2013 The resettlement programme of the Wonorejo Dam project in Tulungagung, Indonesia: the perceptions of former residents, *International Journal of Water Resources Development* 29:1 14-24 DOI: 10.1080/07900627.2012.743432

[6] Chow V T 1959 *Open-Channel Hydraulics International Student Edition* (New York: McGraw-Hill Book Company, Inc) p 98-114, p 157.

[7] Aleksander K.Nicał, Wojciech Wodyński 2016 Enhancing Facility Management through BIM 6D *Procedia Engineering* Volume 164 Pages 299-306 https://doi.org/10.1016/j.proeng.2016.11.623

[8] Donny Harisuseno, Dian Noorvy Khaeruddin, Riyanto Haribowo 2019 Time of concentration based infiltration under different soil density, water content, and slope during a steady rainfall. *Journal of Water and Land Development* no 41 61 – 68 DOI 10.2478/jwld-2019-0028

[9] Ery Suhartanto, Evi Nur Cahya, Lu’uil Maknun 2019 Analisa Limpasan Berdasarkan Curah Hujan Menggunakan Model Artifical Neural Network (ANN) di Sub Das Brantas Hulu. *Jurnal Teknik Pengairan: Journal of Water Resources Engineering* 10 (2) 134-144 DOI: http://dx.doi.org/10.21776/ub.pengairan.2019.010.02.07

[10] Qing-Jie Wen, Zi-Jian Ren, Hui Lu, Ji-Feng Wu 2021 The progress and trend of BIM research: A bibliometrics-based visualization analysis *Automation in Construction* Volume 124 103558. https://doi.org/10.1016/j.autcon.2021.103558.