UNDERGRADUATE THESIS

COMPARISON OF 1D, HYBRID 1D-2D, AND 2D MODELING FOR DAM-BREAK FLOW: CASE STUDY WAY-ELA DAM, INDONESIA

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NPM : 6102001159

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ABSTRACT

Dam-break events are extremely dangerous and cause hazardous floods to the downstream area. To reduce the damages, an evacuation plan is needed, which can be devised by means of dam-break analysis. This study analyzes the flood inundation area with hydraulic numerical modeling consisting of 1D, hybrid 1D-2D, and 2D models. As a case study, a dam-break event of the Way-Ela dam in Indonesia that occurred in 2013 is selected. The Way-Ela dam that was a natural dam and formed by landslides in 2012 due to heavy rainfall, failed in 2013 caused by piping after a heavy rainfall case. The analyzes of hydraulic modeling are done to produce inundation area, water level, and velocity of the flood. The comparison results will be represented with 5-pointed location in the inundation area. After the numerical analysis was done, the accuracy of each model was discovered by validating the results with the observed data. The analysis was conducted with HEC-RAS software. The results showed that the 2D model produced the most accurate results.

Keywords: Dam-Break Flow Analysis, HEC-RAS, Hydraulic Analysis, Hydraulic Numerical Modeling, Way-Ela Dam

PERBANDINGAN ANTARA PERMODELAN 1D, *HYBRID* 1D-2D, DAN 2D UNTUK DEBIT KERUNTUHAN BENDUNGAN: STUDI KASUS BENDUNGAN WAY-ELA, INDONESIA

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ABSTRAK

Terjadinya peristiwa keruntuhan bendungan dapat sangat membahayakan dan menyebabkan banjir yang sangat berbahaya terhadap daerah hilir. Dalam upaya mengurangi dampak kerusakan, diperlukan adanya rencana evakuasi yang dapat dirancang dari analisis keruntuhan bendungan. Studi ini menganalisa daerah genangan banjir dengan permodelan numerik hidraulik yang terdiri dari model 1D, *hybrid* 1D-2D, dan 2D. Studi kasus yang digunakan merupakan bendungan Way-Ela di Indonesia yang telah runtuh pada 2013. Bendungan Way-Ela merupakan bendungan alami yang terbentuk dari longsoran akibat hujan deras pada 2012, yang kemudian runtuh akibat *piping* setelah hujan deras. Hasil analisis dai permodelan numerik hidraulik diantaranya yaitu daerah genangan banjir, ketinggian air, dan juga kecepatan banjir. Perbandingan dari hasil permodelan akan direpresentasikan dengan 5 titik lokasi pada daerah genangan banjir. Akurasi dari ketiga model didapatkan setelah membandingkan hasil analisis dengan data terukur. Analisis dilkakukan dengan perangkat lunak HEC-RAS. Dari hasil analisis yang telah dilakukan, model 2D menghasilkan hasil yang paling akurat.

Kata Kunci: Analisis Debit Keruntuhan Bendungan, Analisis Numerik Hidraulik, Bendungan Way-Ela, HEC-RAS, Permodelan Numerik Hidraulik

PREFACE

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Bandung, 22 December 2023

Metta Lim
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ANNONATIONS

A	:	Total cross-sectional area (m^2)
$\bar{B}$	:	Breach average width (m)
B_{wbot}	:	Bottom width of the breach (m)
c_f	:	Bottom friction coefficient
g	:	Acceleration of gravity (9.80665 m/s^2)
h	:	Hydraulic depth (m)
h_b	:	Final breach height (m)
H	:	Water surface elevation (m)
k_o	:	1.3 for overtopping, 1.0 for piping
q	:	Inflow per unit height (m^2/s)
q	:	Source/sink flux term (m)
Q	:	Total discharge (m^3/s)
R	:	Hydraulic radius (m)
S_f	:	Friction slope
S_h	:	Added force term
t	:	Time (s)
t_f	:	Total duration of the breaching process (s)
u	:	Velocity components in the x- direction (m/s)
v	:	Velocity components in the y- direction (m/s)
v_t	:	Turbulent eddy viscosity (m^2/s)
V	:	Breach average width (m)
V_w	:	Water volume above the breach bottom at the time failure (m^3)
x	:	Distance (m)
z_s	:	Water surface elevation (m)
η_{cl}	:	Elevation of the square centerline (m)
η_{rsv}	:	Reservoir water elevation (m)
η_{up}	:	Top elevation of the square (m)
η_{wbot}	:	Bottom elevation of the breach (m)
f	:	Coriolis parameter (s^{-1})

ρ	:	Water density (kg/m^3)
τ_s	:	Wind surface shear stress (kg/m/s^2)

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CHAPTER 1
INTRODUCTION

1.1 Background

A dam is a structure that is built across the river to collect water until it reaches a certain capacity for single or multi-purposes such as flood control, water management, irrigation, etc. The capacity of a dam is determined based on contour and levees elevation which water should not overtop. In that case, a dam would be designed and constructed with a spillway to prevent overtopping; yet, a natural dam cannot have a spillway since it is formed by natural processes such as landslides, glacial ices, and moraines (Costa and Schuster, 1987). Natural dams have more potential to fail considering how porous and unconsolidated the embankment is which makes natural dams short-termed as in Way-Ela Dam, Central Maluku, Indonesia (Yakti et al. 2018). According to National Plan Disaster Management (NPDM, 2011), Whether it is a natural or a constructed dam, both natural and anthropogenic causes can trigger dam failure which lead to hazardous flood with most of the failure modes are overtopping (70,9%) and piping (14.3%).

Most of the soil in Indonesia is unconsolidated and prone to earthquakes which is why majority of constructed dam in Indonesia is either rock or earth fill embankment such as Jatibarang Dam in Central Java Province and Situ Gintung Dam in Banten Province. Other than constructed dams, Indonesia also has natural dams majorly caused by landslides such as Way-Ela dam in Central Maluku Province. Fill embankments and natural dams tend to have porous soil which is highly risky of overtopping and piping (Awal et al., 2011). The failure of Situ Gintung Dam in Indonesia that has occurred in 2009 caused a significant loss to the downstream village which led to authorities paying more attention to these issues.

This study investigates dam-break flows using numerical hydraulic modeling. In this regard, flood propagation, as an effect of the breaching process, can be simulated in the form of water level progression and flood flow/stage hydrographs with unsteady flow. From the simulation results, the authorities may be informed about how to mitigate the damage to reduce the risk of dam-break event.

According to Government of United Kingdom (GOV.UK, 2023), generally speaking, hydraulic modeling covers some areas such as simulations of pipe network, floodplains, tidal system, and water level and velocity in river channels. Based on flow direction, hydraulic modeling may consist of one-dimensional (1D), two-dimensional (2D), hybrid 1D-2D, and three-dimensional(3D) simulations. 3D modeling has the most complex processes and excessive computational times among others, which is rarely an option aside from its capability of providing more detailed outputs.

One-dimensional (1D) model has the simplest mathematical equation in hydraulic modeling as the output is only in one-direction vector. 1D model is preferable to calculate flows with certain cross-section data of river channels, well-defined valleys, and floodplain with storage areas. Generally, 1D model is more competent in representing small hydraulic structure and in-channel hydraulics than 2D model (HEC-RAS, 2023a). It was noted in (Mark et al., 2004) that although 2D model has more complex numerical approximation, 1D model is more accurate to calculate the flow in a channel where water flows along the channel and does not surpass its levee (Mark et al., 2004). So, one may expect that, 1D model is more accurate and less complicated than 2D model, when the water flows mostly in one direction.

Aside from the complexity of two-dimensional (2D) model, it generally has more detailed outputs compared to 1D model especially in providing velocity distribution. 2D model can calculate flood propagation in lateral or longitudinal directions with the shallow water equations in a numerical approximation (Antonia Sebastian et al., 2022). Compared to 1D model, 2D model is suitable for complex floodplains and direct rainfall modeling, in which water flows in both lateral and longitudinal directions. Figure 1.1 shows 1D and 2D model domain differences. However, simulation time needed for 2D model is much longer than the 1D one as the output of datasets are large (Gharbi et al., 2016).

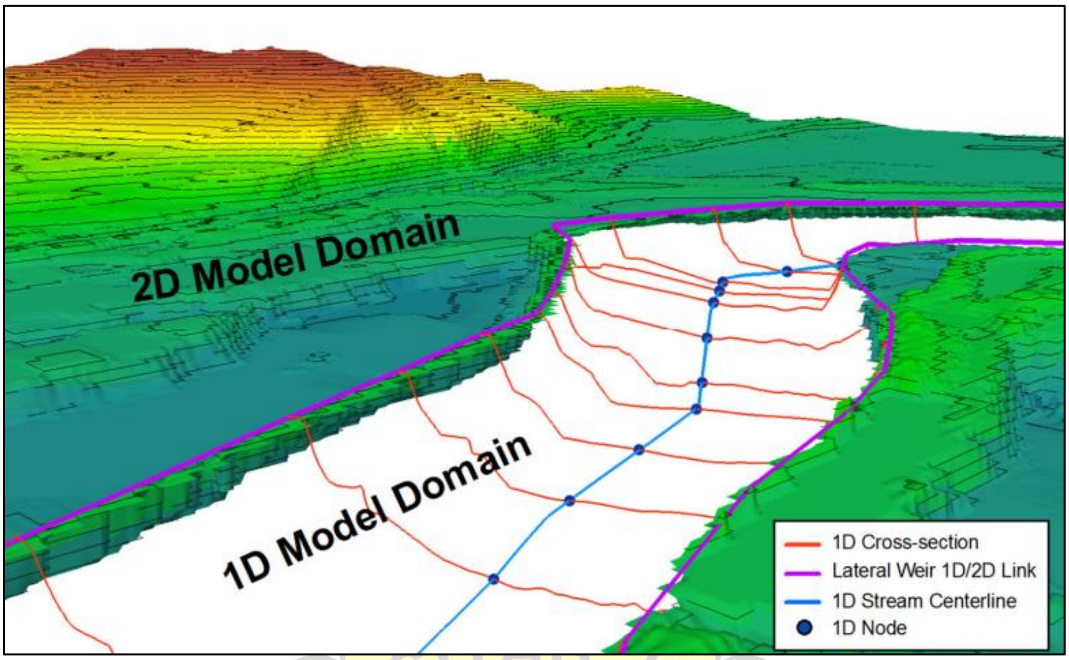

Figure 1.1 Depiction of General 1D Model of the River Channel Coupled with a 2D Model of the Floodplain (Gilles et al., 2012)

To carry out dam-break flow numerical simulations, breach parameters such as final breach shape and total breaching duration are required (Froehlich, 2008). The calculation of breach parameters can be done with several approaches. In this study, the empirical formula of Froehlich (2008) method is used to determine the breach parameters.

After conducting dam-break simulations, potential damages can be mitigated, that is, by means of emergency evacuation plan that is usually accommodated by the government. Nowadays, it is mandatory to provide an emergency evacuation plan for each dam built in Indonesia. Later, such a plan can be integrated into an early warning system, which is a series of systems to alert people of potential disaster. In early warning system, model accuracy is not the only focus but also computation efficiency to make quick responses in some cases such as disasters that might happen in a range of 40 minutes (Suwanno et al., 2023).

This study will analyze the accuracy of 1D, hybrid 1D-2D, and 2D hydraulic modeling by comparing the results with the observed data, namely depth and velocity as well as the computational time. Finally, it is expected to draw a conclusion emphasizing a trade-off between computational time and accuracy among these models.

1.2 Study Objectives

The objectives from this study are defined as follows:

1. To analyze the Way-Ela dam-break flow with piping mode using 1D, hybrid 1D-2D, and 2D hydraulic modeling.
2. To compare the 1D, hybrid 1D-2D, and 2D model results with the observed data.
3. To compare the accuracy of 1D, hybrid 1D-2D, and 2D models in simulating the Way-Ela dam-break case.

1.3 Scope of Study

In this study, the scope of discussion is limited by:

1. The dam-break flow analysis is calculated with 1D, hybrid 1D-2D, and 2D models using the empirical formula of Froehlich (2008), as already provided in the previous research of Kieswanti (2023).
2. The analysis is limited to Way-Ela dam-break case that is located in Negeri Lima Village, Central Maluku Regency, Indonesia.
3. The modeling is carried out with HEC-RAS version 6.1.

1.4 Research Methodology

The research methodology used in this study is explained as follows:

1. Literature Study

   The literature study is done to understand the concept of 1D, hybrid 1D-2D, and 2D modeling, and how the Way-Ela dam-break event occurred according to several previous studies.
2. Data Collection

   The data collection is done to execute the calculations needed for 1D, hybrid 1D-2D, and 2D modeling such as:
   - Digital Elevation Model (DEM)
   - Breach outflow calculation (Kieswanti, 2023)
   - Obeserved data
   - Manning’s n value (Bhola et al., 2018)
3. 1D, Hybrid 1D-2D, and 2D Model Analysis

The 1D, hybrid 1D-2D, and 2D model analysis are done to obtain the water level, velocity, and inundation area. The outputs will then be compared with one another.

4. Data Validation

   The data validation is done to compare the inundation data results from 1D, hybrid 1D-2D, and 2D model modeling with the observed data.

5. Conclusion and Recommendation

   The conclusion is made based on the output comparisons between 1D, hybrid 1D-2D, and 2D modeling. The recommendation is made for the future study based on the conclusion.

The research methodology is shown in flowchart, see Figure 1.2.

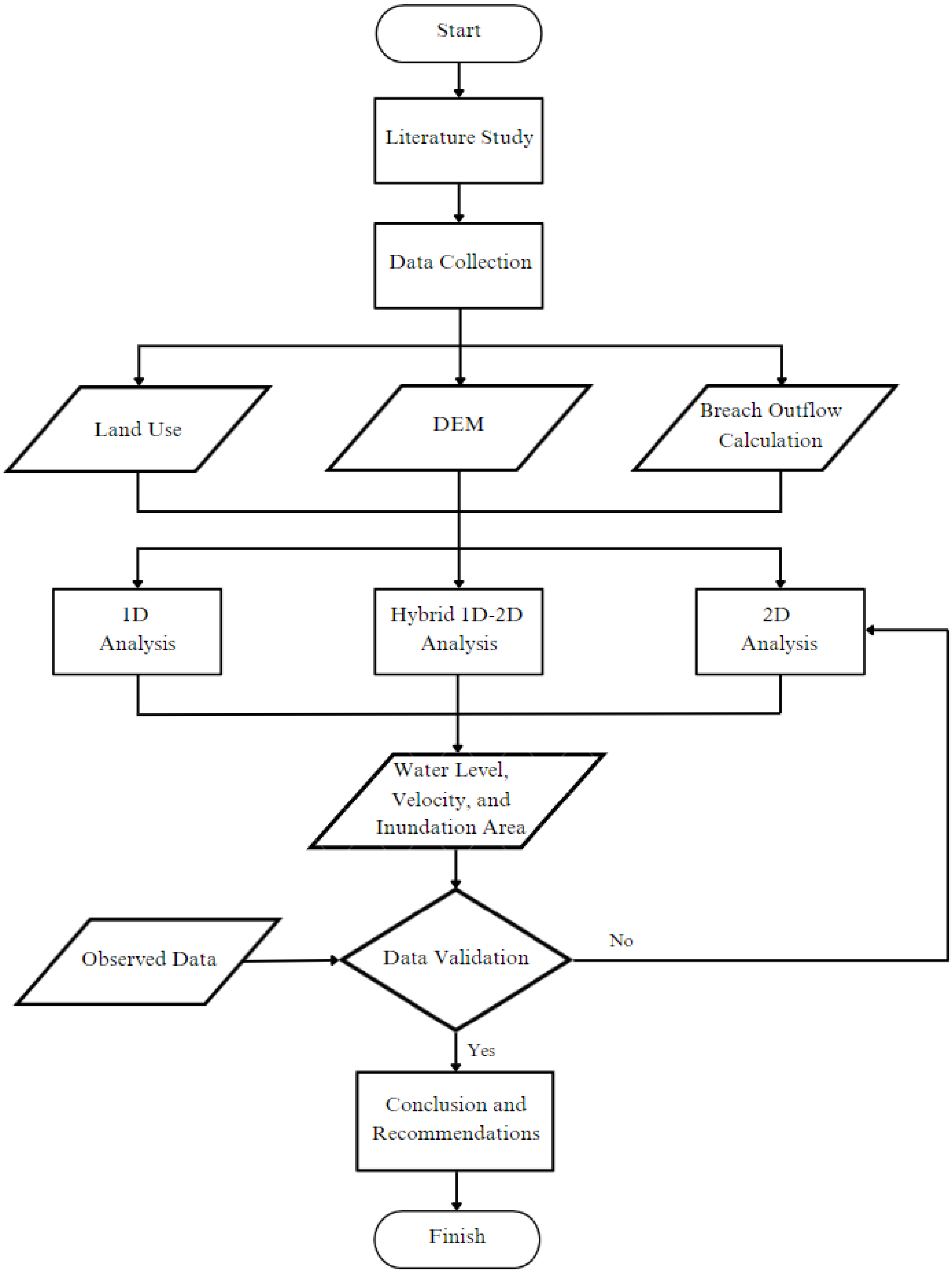

Figure 1.2 Flow Chart