UNDERGRADUATE THESIS

COMPARISON OF TSUNAMI SIMULATION USING DIFFUSIVE AND FULLY-DYNAMIC SHALLOW WATER EQUATIONS MODELS USING HEC-RAS 6.1

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COMPARISON OF TSUNAMI SIMULATION USING DIFFUSIVE AND FULLY-DYNAMIC SHALLOW WATER EQUATIONS MODELS USING HEC-RAS 6.1

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Tanggal: 24 Januari 2022

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ABSTRACT

This study highlights a comparison between the diffusive and fully-dynamic shallow water equations (SWE) for tsunami simulations using HEC-RAS 6.1. The case study used is the 2011 Japan Tohoku Tsunami recorded in the Hilo Bay, Hawaii. For the numerical simulations, three grid sizes of 10, 20, and 30 meters are used. The numerical results, i.e., velocity and water surface elevation, are compared with the benchmark data to ensure the model accuracy produced by the software. The results show a significant delay in the wave arrival time for both equations employed. However, using the fully-dynamic SWE results in a longer delay than the diffusive SWE. The fully-dynamic SWE compute the wave amplitude more accurately than do the diffusive SWE, although both approaches are not still in agreement with the benchmark data. The significant difference in both equations lies in the location of the maximum velocity value. Changing the grid sizes for both equations only increase the computational cost without giving any significant difference. It can be concluded that using both equations does not produce any accurate results compared to the benchmark data, although the differences between each equation are significant for some parameters. The inaccuracy of the results is hypothetically because HEC-RAS 6.1 uses the sub-grid bathymetry approach, by which the mesh calculation takes place at the sub-grid level. This approach is possibly not suitable to be applied to shock wave cases, which in this report is the tsunami wave.

Keywords: Tsunami Simulation, Numerical Modeling, Diffusive Shallow Water Equation, Fully-Dynamic Shallow Water Equation, HEC-RAS 6.1, Grid Size

PERBANDINGAN HASIL MODEL ALIRAN DANGKAL DIFUSIF DAN DINAMIK DALAM KASUS PEMODELAN SIMULASI TSUNAMI MENGGUNAKAN HEC-RAS 6.1

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ABSTRAK

Dalam skripsi ini dipaparkan perbandingan hasil antara model aliran dangkal difusif dan dinamik untuk pemodelan tsunami. Studi kasus yang digunakan adalah tsunami Tohoku Jepang pada tahun 2011 yang tercatat di Pelabuhan Hilo, Hawaii, dimana simulasi dilakukan dengan perangkat lunak HEC-RAS 6.1 menggunakan ukuran grid 10, 20, dan 30 meter. Hasil pemodelan simulasi, yaitu kecepatan dan elevasi muka air, dibandingkan dengan data pengamatan yang sudah terverifikasi. Hasil simulasi menunjukan adanya keterlambatan pada waktu datangnya gelombang tsunami untuk kedua persamaan, namun persamaan dinamik menunjukan keterlambatan yang lebih lama daripada persamaan difusif. Untuk perbandingan amplitudo, persamaan dinamik memberikan hasil yang lebih baik walaupun tidak signifikan terhadap data pengamatan. Perbedaan yang signifikan antara kedua persamaan tersebut dapat dilihat pada lokasi perambatan kecepatan maksimum. Dapat disimupulkan bahwa penggunaan kedua persamaan tersebut tidak memberikan hasil yang akurat apabila dibandingkan dengan data pengamatan, walaupun dalam beberapa parameter, kedua persamaan tersebut menghasilkan perbedaan yang cukup signifikan. Penulis berhipotesa bahwa penyebab dari ketidaktelitian yang dihasilkan HEC-RAS 6.1 adalah penggunaan pendekatan *sub-grid bathymetry* dalam menghitung komponen aliran pada setiap gridnya. Pendekatan ini mungkin kurang cocok digunakan untuk simulasi gelombang kejut, dalam hal ini yang terdapat pada gelombang tsunami.

Kata kunci: Simulasi Tsunami, Model Numerik, Persamaan aliran dangkal difusif, Persamaan aliran dangkal dinamik, HEC-RAS 6.1, Ukuran Grid

PREFACE

Praise to God for His blessing that I am able to complete this thesis, which was made as a requirement to obtain a bachelor's degree from the Parahyangan Catholic University. The topic is "Comparison of Tsunami Simulation Using Diffusive and Fully-Dynamic Shallow Water Equations Models Using HEC-RAS 6.1". During completing this thesis, I received massive support from people in various ways. Hence, I would like to express my gratitude to:

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This thesis may have lots of limitations, and thus in the context of improvement, I highly appreciate any suggestions. Hopefully, this study is beneficial for the readers.

Bandung, January 2022

Rifa Amaliah

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CHAPTER 1
INTRODUCTION

1.1. Background

A tsunami is a series of ocean waves or a wave train with a very long wavelength caused by any disturbance that is capable of moving huge water masses. Some of the triggers are submarine earthquakes, volcanic eruptions, and landslides. Tsunami waves are characterized as a shallow-water wave, a wave in which the wavelength is much longer than the depth of the water (International Institute for Geo-Information Science and Earth Observation (ITC), 2005). The average wavelengths in a normal ocean are about a hundred meters, whereas, for tsunamis, the wavelengths can exceed up to 500 km. However, as the tsunami waves approach the coast, due to the shoaling effect, the wavelengths decrease, and the waves grow in height (Zhao, Wang, & Liu, 2012).

Tsunami events can cause severe destructions and large numbers of fatalities. In 2004, about 230,000 deaths were resulted from the Indian Ocean earthquake measured 9.3 on the Richter scale that caused a tsunami in Banda Aceh (Parwanto & Oyama, 2014). The amount of economic loss due to the extensive damage in Banda Aceh was estimated to be US$4.5 billion, with the total post-tsunami reconstruction cost of up to US$7 billion (Badan Rehabilitasi & Rekonstruksi (BRR) and The World Bank, 2005). On the other side, a magnitude of 9 on the Richter scale earthquake that occurred below the north Pacific Ocean caused a tsunami in 2011, that is the Great East Japan Earthquake and Tsunami disaster. This disaster resulted in over 19,000 deaths and damaged more than 200,000 buildings and houses, estimating the direct economic loss of USD$309 billion (Nanto, Cooper, Donnelly, & Johnson, 2011).

One can see that these aforementioned events are similar regarding the size of the earthquake. However, the impacts on fatality are pretty different. One of the possible reasons for this is the unequal level of readiness (Koshimura, 2015). Hence, the preparation for future hazardous events is of uttermost importance in order to minimize the number of casualties and physical damages, for instance, preparing a proper early warning system. An early warning system is an integrated system that requires coordination between numerous institutions enabling every person to minimize any risk in catastrophic events. In 2018, around 1,252 lives were lost during the tsunami event in Palu, Central Sulawesi, Indonesia, which led to a criticism of the failure of the Indonesia Tsunami Early Warning System (InaTEWS). A short time after, the United Nations Office for Disaster Risk Reduction (UNDRR) published a study analyzing several issues that contributed to the failure of InaTEWS in Palu.

The first obstacle faced was the technology limitation, wherein the Palu Incident, the tsunami wave arrived earlier than the one the Indonesian Agency for Meteorological, Climatological, and Geophysics (BMKG) had predicted. As a matter of fact, the BMKG also miscalculated the incoming wave height and estimated it lower than the actual scenario. It was suggested that the used system is ineffective for tsunamis with an arrival time below 10 minutes (UNDRR and UNESCO-IOC, 2019). The second issue is the long process needed in delivering the warning to the affected communities, reducing the golden time that is supposed to be spent precisely.

In this thesis, analyzing the tsunami propagation process will be identified as the primary focus of the study, and there are three ways to learn it. The first one is through historical tsunami events, where the data recorded after the tsunami is an essential aspect of studying the tsunamis. Various equipment is needed to gather the data, such as bottom imaging, earthquake instruments, and tide gauges in harbors. Secondly, a prototype wave is possible to be reproduced by building a physical model, and this model is believed to be the best instrument to simulate the complex flow of tsunami waves (Briggs, Yeh, & Cox, 2008). The last one, as computer development increased in the last few decades, numerical models have been used massively to simulate tsunami propagation accurately. Therefore, this particular model is about to be used to simulate the tsunami propagation in this study.

To simulate the tsunami propagation using a numerical model, the freeware program HEC-RAS 6.1 will be utilized. HEC-RAS is a program developed by the U.S. Army Corps of Engineers (Hydrologic Engineering Center) with the U.S. Federal Government resources. This software can perform 1D and 2D hydrodynamic calculations, spatial mapping, and water quality modeling (Brunner, 2021). For this study, the author intends to compare the Diffusive and Fully-Dynamic Shallow Water Equations (SWE) to identify the most optimal result, considering that using the Diffusive SWE might decrease the computational time. Furthermore, to support the entire process of this research, the data from the Japan Tohoku Tsunami in 2011 recorded in Hilo Bay, Hawaii, that have been calibrated will be used.

1.2. Objective

This thesis aims to learn the process of the tsunami wave propagation by means of numerical modeling. The objectives of this thesis are:

1. To perform the tsunami simulations using HEC-RAS 6.1 freeware using two different equations: Diffusive and Fully-Dynamic SWE.
2. To perform the tsunami simulations using HEC-RAS 6.1 with several grid sizes.
3. To analyze and compare the results of all the simulations computed with the benchmark data provided.
4. To determine whether HEC-RAS 6.1 is capable of performing tsunami simulation based on several aspects, one of which is the trade-off between the running time and accuracy for both Diffusive and Fully-Dynamic SWE models.

1.3. Scope of Study

This thesis focuses on the tsunami simulation performed using HEC-RAS 6.1. The tsunami data[1] used for the study is the Japan Tohoku Tsunami in 2011 recorded in Hilo Bay, Hawaii, around 7 hours post-earthquake. However, in order to maintain the stability factor for the numerical modeling, the author extends the computational

[1] See: http://coastal.usc.edu/currents_workshop/problems/prob2.html

time up to 3 hours, and thus it will be performed at 4 hours until 13 hours post-earthquake. The simulation is carried out using both Diffusive and Fully-Dynamic SWE with several computational grid sizes of 10 m, 20 m, and 30 m. The results of this simulation are provided in two parameters, i.e., velocity and water surface elevation, and they will be compared with the benchmark data.

1.4. Research Methodology

The research methodology for this thesis consists of:

1. Literature Review

   This step is implemented to understand the concepts about the study according to some sources.
2. Data Analysis

   This step is carried out to process the raw data provided on the website to be used as input in the next step.
3. Numerical Modeling

   This step is carried out to calculate and perform the tsunami simulation using the numerical model HEC-RAS 6.1.
4. Result Analysis

   This step is taken to analyze and conclude the results of all simulations computed.

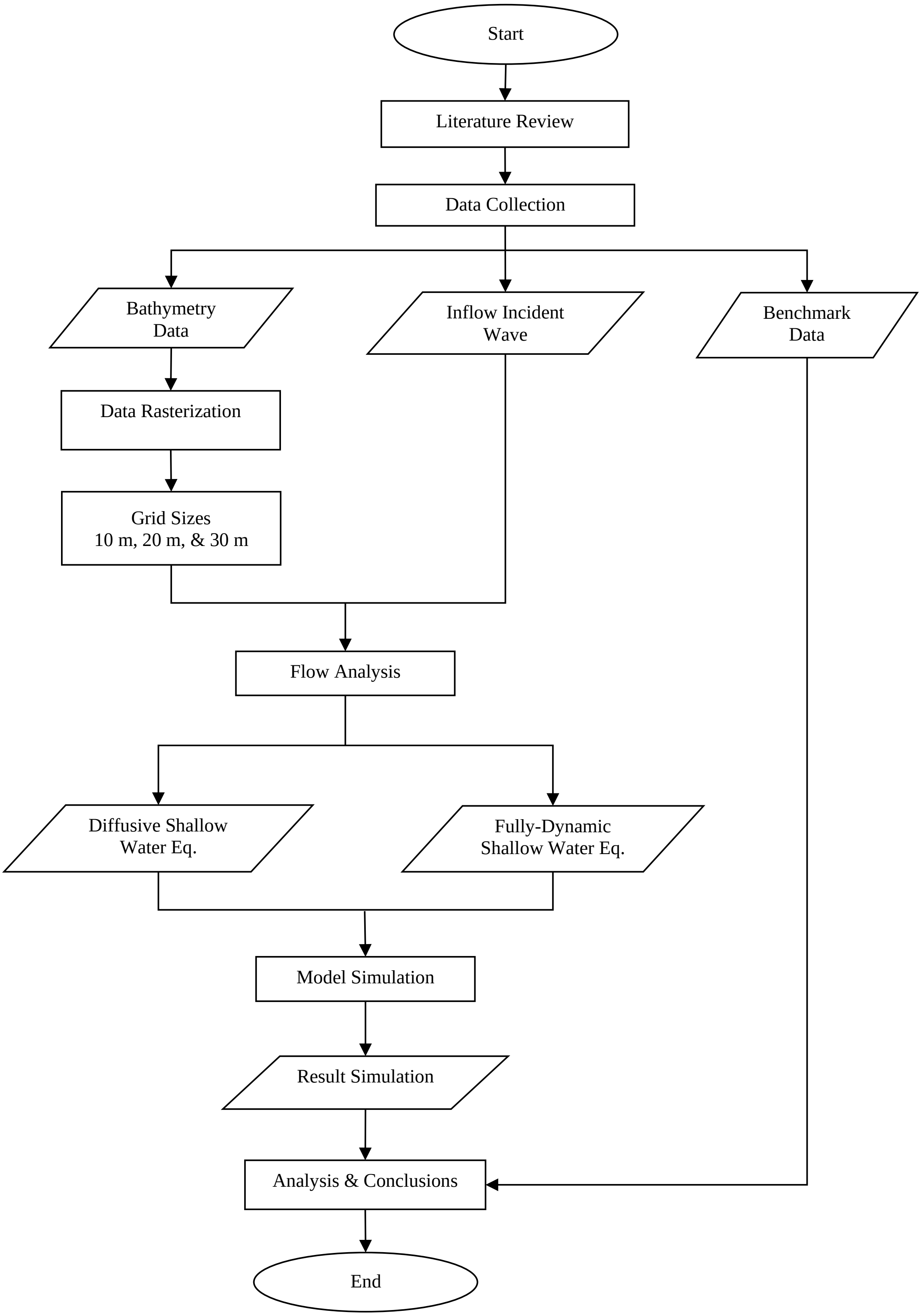

Figure 1.1 Flow Chart