The Utilisation of the Numerical Hydrodynamic Model to Face Rob Floods in Coastal Areas in the Industrial Revolution Era 4.0 at East Java Indonesia

S Hermawan, O Hans, C Gunawan, D Tjandra and J Purnomo

Civil Engineering Department, Petra Christian University, Surabaya 60236, Indonesia
shermawan@petra.ac.id

Abstract. Global warming has impacted the sea-level rise. Then it caused the Rob flooding in coastal areas. The research location is in Rob floods area in Tegalsari Hamlet, Jabon Subdistrict, Sidoarjo that have damaged seaweed cultivation, and estimated losses reached 5 billion rupiahs in early 2018. Therefore, it needs to do research numerical hydrodynamic models to prevent this flood. However, the devices for measurement data are too expensive. This research aims to utilise economical devices measurement based on the industrial revolution 4.0 with numerical hydrodynamic methods models in the field of civil engineering. This model is an approach to estimate the hydrodynamics of coastal waters such as tides, currents and water levels. To simulate the hydrodynamic model, for nearshore bathymetry data are gained from sonar and offshore bathymetry data from GEBCO. The simulations utilise open-source Delft3D software using the Navier-Stock formula. The outcomes prove that hydrodynamic simulation models can be used to estimate sea-level rise for the next few years in coastal areas. Thus, the determination of the type of construction of civil engineering buildings that are strong and environmentally friendly so that publics do not cause huge losses and make coastal communities resilient to disasters.

Keywords: industrial revolution 4.0, numerical hydrodynamic model, rob flood

1. Introduction

Rob floods are floods caused by rising sea levels on land. The impacts of Rob floods are damage to vehicles/work equipment, damage to ponds, loss of land, water salinity, and the most severe damage to residential buildings [1]. To overcome the Rob flood, many ways can be done, including the construction of a civil engineering structure in the form of a retaining wall. Where in the implementation of the construction design requires technical hydrodynamic data. Recently in Indonesia, the collection/measurement of primary data such as bathymetry for hydrodynamic modelling is still very expensive. For this reason, the challenge for planners and academics is to find solutions to the impacts caused by rising sea levels which supported by research cheaper tools along with robust data.

The background to the problem in this study originated from field observations conducted on January 25, 2018, in Sidoarjo, East Java. Based on several interviewees, it confirmed that the Rob Flooding occurred in Tanjung Sari Village, Jabon District. On December 1, 2017, there was a large tide that caused a dyke in the Kali Alo hamlet. On December 3, 2017, Rob Flood began entering residents' houses in Kali Alo Hamlet. From 5 to 9 December 2017, Rob Flood also hit 40-50 cm in Tanjung Sari Hamlet. Right on December 9, 2017, the embankment in Tanjung Sari Hamlet collapsed due to the Rob Flood
which resulted in the loss of fish in ponds and seaweed that failed to harvest. The loss estimated at up to 5 billion rupiahs [2].

This research study goal is to apply the 4.0 industrial revolution-based research device in the field of civil engineering for near-shore bathymetry data measurement. Then, this data can be processed as an input parameter to produce a robust hydrodynamic simulation model.

2. Material and Method

2.1. Simulation of Numerical Hydrodynamics Model with Delft3D Open Source

The numerical hydrodynamic model is an approach to estimate the hydrodynamic movement of water over time in a particular region. Since 1994, the 2D model carried out with several different modules, including hydrodynamics, water quality, and eutrophication used for modelling the hydrobiological and hydrochemical processes [3]. Delft3D software is an open-source software developed by Deltares and is an encouragement for experts from all over the world to further develop modelling. Delft3D is a multi-dimensional hydrodynamic simulation or modelling program that has functions for calculating waves, river flow, sediment, water quality, and ecological analysis in coastal areas [4].

As can be seen in Figure 2, the Flow module in Delft3D is a multi-dimensional 2D and 3D hydrodynamic that simulates a program for calculating dynamic flow phenomena due to tides and meteorologists on linear curves, thus requiring a grid. The equations are solved numerically using the orthogonal horizontal coordinate arch system which provides a good grid installation with the shape of the area being modelled [5]. Grid is a coordinate line of vertical and horizontal direction to determine the area of the simulated area or set the boundary area consisting of two systems, namely rectangular coordinate cartesian and spherical coordinate. The coordinate cartesian system is rigid and only has parameters namely the vertical direction ($\eta$) and horizontal direction ($\xi$), while the spherical coordinate system follows the contour line of the earth's surface which has two parameters namely direction and height, with latitude ($\alpha$) having positive values to the north and longitude ($\phi$) which is positive eastward as shown in Figure 1.

![Figure 1. Spherical coordinate system (a) and cartesian coordinate system (b) [6]](image)

A finite-difference grid equation can also solve the determinant diffraction equation in the appropriate combination of initial arrangements. To complete the modelling of currents and tides. The Delft3D system uses the Navier-Stokes equation in its calculations. According to Navier Stokes's formula [7] is:

$$ \frac{\partial \mathbf{p}}{\partial t} + \frac{\partial (\mathbf{pu})}{\partial x} + \frac{\partial (\mathbf{pv})}{\partial y} + \frac{\partial (\mathbf{pw})}{\partial z} = 0 $$

(1)

2.2. Tidal Harmonic Constituents

In each group, these components have members as shown in Table 1. Each constituent represents a periodic change or variation in the relative position of the earth, moon and sun. Constituents vary with the position at which tides observed. In this representation, general formulas for astronomical waves can used:

$$ H(t) = A_0 + \sum A_i F_i \cos(\omega_i t + (V_0 + u) t - \phi_i) $$

(2)
Fi and \((V_0 + u)_i\) are time-dependent factors, together with \(\omega\), can be easily calculated and generally arranged in various tidal yearbooks. V0 is a phase correction factor that links the observational timeframe with the internationally agreed-upon celestial timeframe [6].

### Table 1. Tidal constituents that driven the model on Delft3D.

| Symbol | Amplitude (m) | Phase (deg) | Symbol | Amplitude (m) | Phase (deg) | Symbol | Amplitude (m) | Phase (deg) |
|--------|---------------|-------------|--------|---------------|-------------|--------|---------------|-------------|
| M2     | 1.51          | 55.84       | K1     | 0.55          | 312.0       | MM     | 0.01          | 13.67       |
| S2     | 0.67          | 122.7       | O1     | 0.11          | 288.4       | MF     | 0.01          | 21.53       |
| N2     | 0.33          | 15.21       | S1     | 0.20          | 276.2       | M4     | 0.06          | 313.1       |
| 2N2    | 0.25          | 121.0       | P1     | 0.01          | 185.4       | MN4    | 0.05          | 260.5       |
| K2     | 0.55          | 312.0       | Q1     | 0.01          | 13.67       | MS4    | 0.05          | 44.37       |

2.3. Primary Data Retrieval

Primary data collected by direct measurement, including nearshore bathymetry in the vicinity of the research area. This method refers to the method that carried out by [8] who uses sonar hanging from a drone. It carried out by deploying the sonar on a boat that is running a maximum of 5 km/hour (see Figure 3). The advantage of this Sonar, the researcher, can show data in real-time through software from smartphones. On the other hand, the data retrieved cannot directly be used, because it must first be uploaded to the cloud using an account. After uploading, the data can only downloaded through the maps.deepersonar.com website [9].

![Figure 2. Sonar hanging on boat.](image)

2.4. Simulation on Delft3D

After getting river bathymetry data around the study site, it can be continued by entering the data into Delft3D. Figure 4 shows the grid on Delft3D with its result in the form of water level. The spherical grid used in this model has an average size of 500 meters, along with the number of grid 69,901 grids. The offshore bathymetry data collected from the General Bathymetric Chart of the Oceans (GEBCO) [10]. Then, setting up the simulation carry out, after the data information about model development complete, including 15 tidal constituents from BW Geo Hydromatics, wind, viscosity, and manning roughness.
2.5. Validation
The validation or verification phase of a model is needed to check the model results. At this stage validation sources from secondary data will be used, including the ministry of public work and public housing of the Republic of Indonesia and meteorology climatology and geophysics agency. Microsoft Excel software used to conduct the validation. Validation of the simulation results of this model uses Root Mean Square Error (RMSE) formula:

$$\sqrt{\frac{\sum(x_1-x_2)^2}{N}}$$  \hspace{1cm} (3)

3. Result and Discussion
The deeper sonar as a device that is supported by technology based on the industrial revolution 4.0, it can use to retrieve valid nearshore bathymetry data with low rate data measurement. The bathymetry data will input data to create a hydrodynamic model by using open source Delft3D. Then, the hydrodynamic model based on the industrial revolution 4.0 can apply to simulate the Rob flood that has occurred. From the outcomes of simulations that have been done prove that the effect of Manning Roughness and grid size greatly affects the results of the hydrodynamic model at this research location.

The simulation results which generated from these simulations are in the form of water level data. The results are compared with water level data from the ministry of public work and public housing of the Republic of Indonesia and meteorology climatology and geophysics agency. Validation of the results of the Rob flood simulation can be seen in Figure 5. The figure shows that the validation used with the RMSE formula shows the number 0.302 meters, which means a deviation of approximately 0.3 meters or 30 centimetres. Although the RMSE value is too large, the results already have the same pattern. RMSE values can be reduced back by doing a sensitivity analysis to make a more accurate model. The final step in this simulation is Delft3D-Flow for one-year simulation and 2 weeks of extreme condition.

![Figure 3](image.png)

**Figure 3.** Development of the Delft3D grid model and The Result of Water Level.

4. Conclusions
After carrying out this research project by direct measurement data on the field along with numerical hydrodynamic simulation models can be concluded that
1. The industrial revolution based technology 4.0 in the sonar can be used to retrieve valid primary data.
2. Manning Roughness and grid size have a significant effect on the process set up the model of the numerical hydrodynamic simulation model.
3. The use of numerical hydrodynamic models based on the industrial revolution 4.0 can be used as a reference in the design of construction to deal with Rob floods
4. The validation obtained from the results of this simulation shows the RMSE value of 0.302, this means that the resulting model is approaching what is happening in the field.

**Figure 4.** Validation of simulation results with water level data from *sealeveling* websites.

**Acknowledgement**

The authors would like to express appreciation for the support of the sponsors of Petra Christian University project number: 01/HBK-Penelitian/LPPM-UKP/IV/2019 and Directorate General of Higher Education Indonesia and Kopertis VIII, project number: 002/SP2H/LT/K7/KM2017.

**References**

[1] Desmawan B and Sukamdi 2012 *Adaptasi Masyarakat Kawasan Pesisir terhadap Banjir Rob di Kecamatan Sayung, Kabupaten Demak, Jawa Tengah*. 1 pp 1-9.

[2] Hartanto A and Purnomo Y 2018 *Analisis dan Aplikasi Ilmu Teknik Sipil dalam Adaptasi Perubahan Iklim Global di Kawasan Pesisir Pantai Sidoarjo Provinsi Jawa Timur*. Jurnal Dimensi Pratama Teknik Sipil 7(2) pp 44-50.

[3] Oldakowski B and Kwiatkowski J 1995 *Forecast model of water quality of Vistula Lagoon* 6, pp 66-258.

[4] Hafli T M 2014 *Simulasi Numerik Perubahan Morfologi Pantai Akibat Konstruksi Jetty Pada Muara Lambada Lhok Aceh Besar Menggunakan Software Delft3D* p4.

[5] Bielecka M and Kazmierski J 2003 *A 3D mathematical model of Vistula Lagoon hydrodynamics - general assumptions and results of preliminary calculations* 80 2-4.

[6] Delft3D-Flow 2014 *Simulation of multi-dimensional hydrodynamic flows and transport phenomena, including sediments* pp 28-31.

[7] Girault V and Raviart PA 1979. *Finite element approximation of the Navier-Stokes equations* p 749.

[8] Bandini F, Jakobsen J, Olesen D, Reyna-Gutierrez J and Bauer-Gottwein P 2017 *Measuring Water Level in Rivers and Lakes from Lightweight Unmmaned Aerial Vechichles*. Journal of Hydrology p3.

[9] Lakebook 2019 [https://maps.deepersonar.com](https://maps.deepersonar.com/) Accessed September 29, 2019.

[10] General Bathymetric Chart of the Oceans 2003 Liverpool [http://www/gebco.net/data and products/gebco digital atlas](http://www/gebco.net/data and products/gebco digital atlas) Accessed September 29, 2019.