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Estimation and Validation of Nearshore Current at the Coast of Carey Island, Malaysia

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ABSTRACT

This study simulates the nearshore current characteristics at Carey Island by using *MIKE 21 Hydrodynamic FM.* The model simulations are calibrated and validated against measured conditions by adjusting the values of bed resistant over the stipulated computation domain. To evaluate the accuracy of the simulation results, three statistical parameters, namely RMSE, R Squared, and Thiel's inequality coefficients are calculated to compare the observed and simulated results. The results indicate that the current speeds during the spring tide are approximately between 0 m/s and 0.64 m/s which come from Northwest to southeast direction. A good agreement between observed and simulated values of current speeds, current direction and water level with R squared of approximately 0.92 to 0.95 are obtained. Results suggest that the bed resistant is an important parameter in the hydrodynamic simulation using *MIKE 21 Hydrodynamic FM*.

Keywords: Bed resistant, current characteristics, estimation, validation, MIKE 21 Hydrodynamic FM

INTRODUCTION

Coastal hydrodynamics is important in the calculation of sediment transport and morphological evolution (Fairley, Davidson, & Kingston, 2009; Fitri, Hashim, Song, & Motamedi, 2016; Hashim, Fitri, Motamedi, & Hashim, 2013; Nam, Larson, & Hanso, 2011; Ranasinghe, Symonds, Black, & Holman, 2004; Roberts, Hir, & Whitehouse, 2000). This information is vital for many coastal engineering design and applications for new retrofittingmeasures of coastal defence structures. Initially,

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characteristic of the coastal hydrodynamics is studied through physical models. However, these models have certain limitations such as selecting the appropriate scale, high cost, randomness of natural phenomena, and non-availability of complete understanding of coastal hydrodynamic behaviour. Therefore, estimations of coastal hydrodynamics rely largely on numerical models supported by physical experiments (Kim & Wang, 1996; Nicholson et al., 1997; Shamji, 2011; Zanuttigh, 2007).

Hydrodynamic numerical models are used to examine the complex systems of the multiple processes in the coastal areas that may occur simultaneously (Toorman, 2001). These models are important for the study of hydraulics (Bolaños, Sørensen, Benetazzo, Carniel, & Sclavo, 2014). Due to the nonlinearity of these systems and irregular domains in the coastal water bodies, a number of numerical models have been developed based on flexible mesh approach which can handle such irregular domains (DHI, 2013; Jones, Petersen, & Kofoed-Hansen, 2007; Wu, Sánchez, & Zhang, 2011).

The main objective of this study was to simulate the current speeds and current directions at the Coast of Carey Island; this information would be useful in designing proper coastal structures around the coastline of Carey Island. The simulations of current characteristics have been carried out using the software package - *MIKE 21 Hydrodynamic FM* (DHI, 2013). In order to provide the best performances of the simulation results, the model was initially calibrated and validated against the measured conditions by adjusting the manning number in the computational domain.

METHODS

Model Input

Data required for the modelling of *MIKE 21 Hydrodynamic FM* consists of bathymetry data from computational domain, wind speeds and wind directions, significant wave heights, mean wave directions and bed resistant. Wind speeds, wind directions, significant wave heights and mean wave directions at the range of latitude 2^o to $3^o30''$ N and longitude 100^o to 102^o were obtained from Meteorology Department of Malaysia.

Bathymetry

Bathymetry survey with fine resolution was conducted along Langat river and around the coast of Carey Island covering an area of approximately 17.5 km x 7 km. The survey activities were carried out during the spring tide from 8th until 12th December 2014. In addition, bathymetry data of the ocean region was generated using C-MAP 2014.

Boundary Condition

Tidal levels at Lumut station (obtained from Department of Survey and Mapping, Malaysia) and Belawan station (obtained from Dinas Hidro-Oceanography, Indonesia) were spatially interpolated to obtain the values of water levels at the north boundary condition, while tidal levels at Tanjung Keling station (obtained from Department of Survey and Mapping, Malaysia) and Dumai station (obtained from Dinas Hidro-Oceanography, Indonesia) were spatially interpolated to find the values of water levels at the south boundary condition (Figure 1).

Model Calibration and Validation

Two units of Acoustic Wave and Current Profiler (AWAC) with 600 Khz frequency were installed at two locations at Carey Island coast between 23th December 2014 and 7th January 2015 (covering spring tide and neap tide). The device was utilised to measure the current characteristics (current speeds and current directions) and water level at 10-minute intervals. Table 1 shows the location of the AWAC.

The current characteristics and water levels recorded at latitude 02˚ 48’ 40.02” N and longitude 101˚ 20’ 11.18” E (AWAC 1) were used for model calibration purposes. Current characteristics and water levels at latitude 02˚ 49’ 26” N and longitude 101˚ 18’ 58.14” E (AWAC 2) were used for validating the calibrated model. Figure 1 shows the flexible mesh in computation domain, boundary condition, locations of the AWAC and locations of the tide stations.

Table 1
Co-ordinate locations of AWAC 1 and AWAC 2

Station	Longitude	Latitude	Depth (m)
AWAC 1	101˚ 20’ 11.18”E	02˚ 48’ 40.02” N	10.324
AWAC 2	101˚ 18’ 58.14” E	02˚ 49’ 26” N	12.557

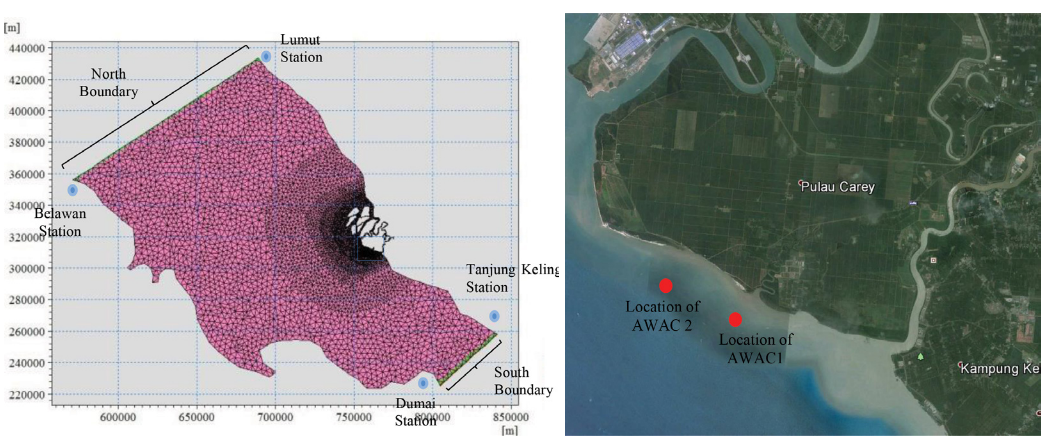


Figure 1. Computational domain used for hydrodynamic simulation and locations of the AWAC and tidal stations

Numerical Model

MIKE 21 Hydrodynamic FM is the basic model of the MIKE 21 software package for free surface flows based on flexible mesh approach. It simulates unsteady two-dimensional (2D) water level variations and flows in the coastal area (DHI, 2013). The flows are calculated in x and y direction based on the solution of depth integrated equations of conservations of volume and momentum. The following equations are the conservation of volume and momentum which describe the flow and water level variations in x and y direction:

X direction of momentum:

$$\frac{\partial \mathrm{p}}{\partial \mathrm{t}}+\frac{\partial}{\partial \mathrm{x}}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial \mathrm{y}}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial \mathrm{x}}+\frac{\mathrm{gp}\sqrt{p^2+q^2}}{C^2h^2}$$

$$-\frac{1}{\rho_w}\left[\frac{\partial}{\partial \mathrm{x}}(h\tau_{xx})+\frac{\partial}{\partial \mathrm{y}}(h\tau_{xy})\right]$$

$$-\Omega q-fVV_x+\frac{\mathrm{h}}{\rho_w}\frac{\partial}{\partial \mathrm{x}}(Pa)=0 \qquad [1]$$

Y direction of momentum:

$$\frac{\partial \mathrm{p}}{\partial \mathrm{t}}+\frac{\partial}{\partial \mathrm{y}}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial \mathrm{x}}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial \mathrm{y}}+\frac{\mathrm{gq}\sqrt{p^2+q^2}}{C^2h^2}$$

$$-\frac{1}{\rho_w}\left[\frac{\partial}{\partial \mathrm{y}}(h\tau_{yy})+\frac{\partial}{\partial \mathrm{x}}(h\tau_{xy})\right]$$

$$-\Omega q-fVV_y+\frac{\mathrm{h}}{\rho_w}\frac{\partial}{\partial \mathrm{y}}(Pa)=0 \qquad [2]$$

$$C\ =Mh^{1/6} \qquad [3]$$

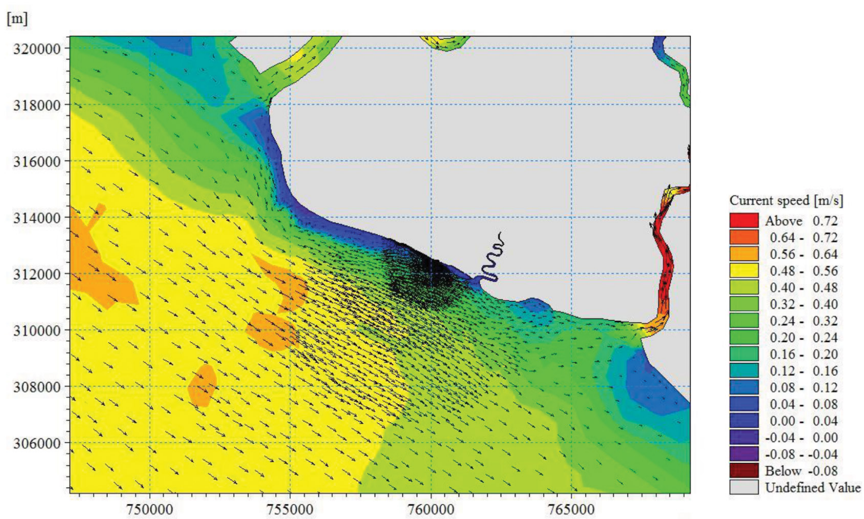
The equation of continuity:

$$\frac{\partial \zeta}{\partial \mathrm{t}}+\frac{\partial \mathrm{p}}{\partial \mathrm{x}}+\frac{\partial \mathrm{q}}{\partial \mathrm{y}}=\frac{\partial \mathrm{d}}{\partial \mathrm{t}} \qquad [4]$$

Where, x, y is space coordinate or direction components, ζ is surface elevation (m), h is water depth (m), d is time varying water depth (m), C is chezy resistance ($m^{1/2}/s$), while M is manning number or bed roughness ($m^{1/3}/s$).), f(V) is wind friction factor while V is wind speed (m/s), g is acceleration due to gravity (m/s^2), Pa is atmospheric pressure ($kg/m/s^2$), ρ_w is density of water (kg/m^3) and τ is shear stress.

RESULTS AND DISCUSSIONS

Figure 2 shows the current characteristics at the coast of Carey Island during spring tide and neap tide between 23rd December 2014 and 7th January 2015. Figure 3 summarises the comparison of predicted and measured current speeds, current directions and water levels at latitude 02˚ 48' 40.02" N and longitude 101˚ 20' 11.18" E. In addition, Figure 4 presents the comparison of predicted and measured current speeds, current directions and water levels at latitude 02˚ 49' 26" N and longitude 101˚ 18' 58.14" E. In order to produce the best performance of the simulation results in hydrodynamic model of *MIKE 21 Hydrodynamic FM* model, the values of bed roughness (Table 2) were used in the computation domain.



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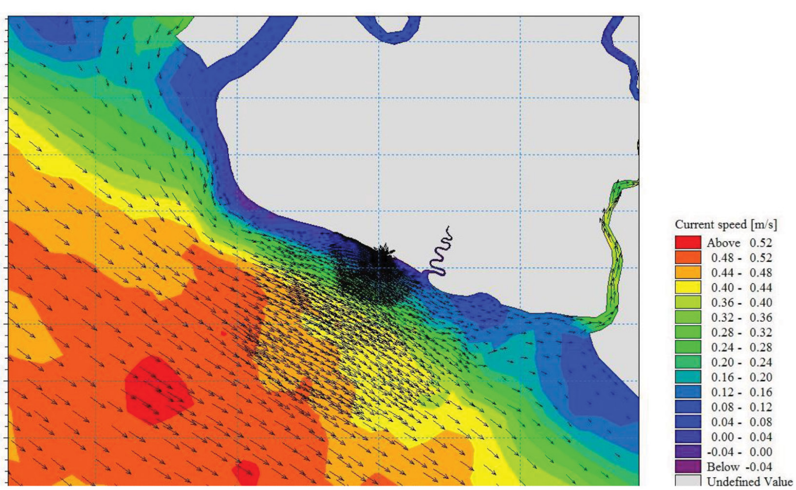
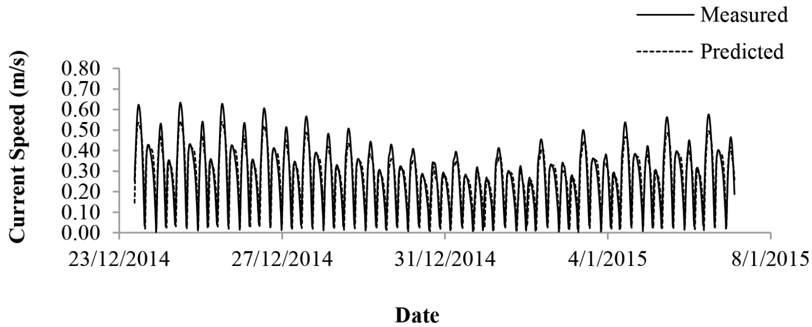


(b)

Figure 2. Current characteristics at the coast of Carey Island, (a) during spring tide, (b) during neap tide



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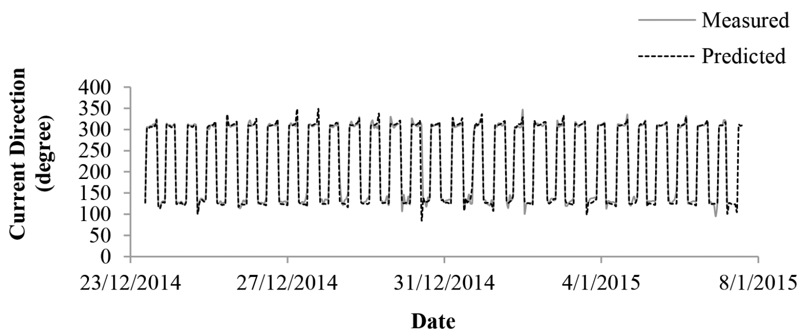

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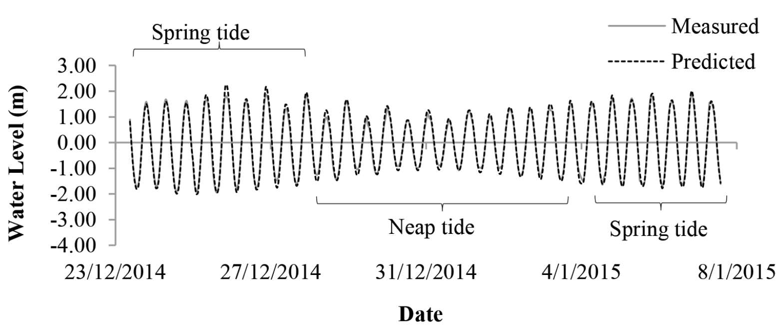
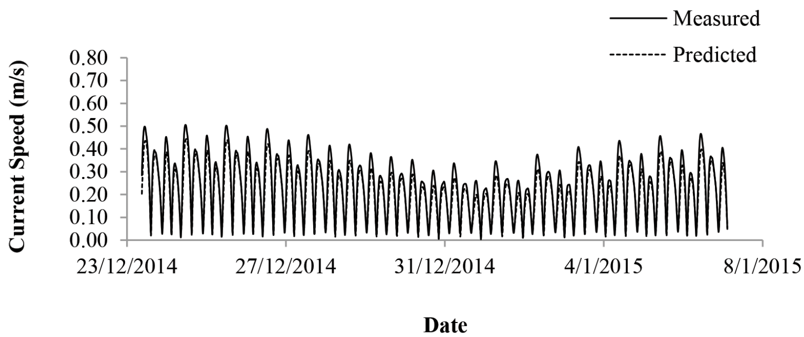


(c)

Figure 3. Comparison between measured and predicted of (a) current speeds, (b) current directions and (c) water levels on 23th December 2014 to 7th January 2015 at latitude 02˚ 48' 40.02" N and longitude 101˚ 20' 11.18" E



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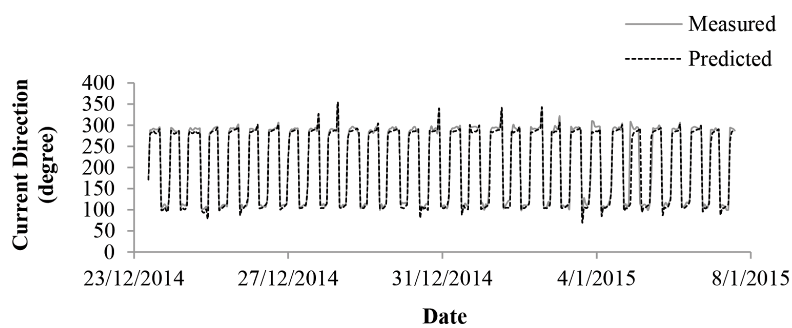

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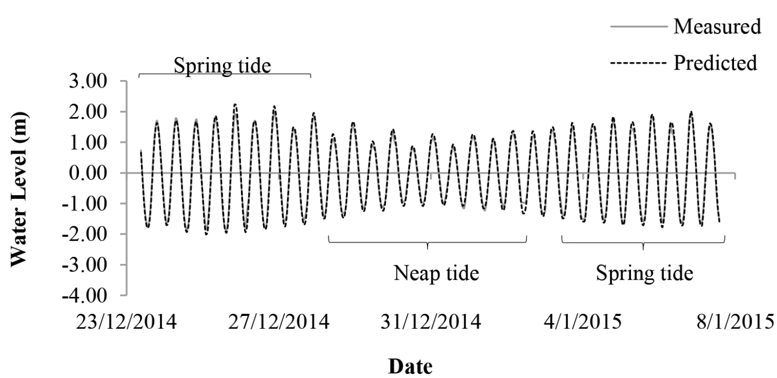

(c)

Figure 4. Comparison between measured and predicted of (a) current speeds, (b) current directions and (c) water levels on 23th December 2014 to 7th January at latitude 02˚ 49' 26" N and longitude 101˚ 18' 58.14" E

Table 2
Bed Roughness used in the computational domain

No	Depth (m)	Manning Number ($m^{1/3}/s$)
1	Less than 15	45
2	15 to 50	40
3	Greater than 50	35

Based on Figure 2, it is evident that the current speeds at the coast of Carey Island during spring tide and neap tide conditions were approximately 0 to 0.64 m/s and 0 to 0.52 m/s, respectively which come from the northwest to southeast direction (125^o). According to Figure 3 and Figure 4, the current speeds, current directions and water levels obtained from hydrodynamic simulations have a good agreement with the field measurement.

Table 3 summarises the minimum values of *RMSE*, R Squared, and Theil's inequality coefficients in model calibration and validation process. The minimum values of *Root Mean Squared Error (RMSE)* for calibration and validation of current speeds and current direction are 0.07 m/s & 15^o and 0.08 m/s & 17^o respectively. Based on standard error allowed for hydraulic study by DID (2013), the *RMSE*, R Squared and Theil's inequality coefficients values prove that the model is well calibrated and validated.

Table 3
Statistical Metrics for hydrodynamic model performance

No	Type of Statistical Metrics	Calibration Process			Validation Process		
		Current Speed (m/s)	Current Direction (degree)	Water Level (m)	Current Speed (m/s)	Current Direction (degree)	Water Level (m)
1	RMSE Values	0.07	15^o	0.11	0.08	17^o	0.10
2	R Squared	0.92	0.91	0.94	0.91	0.92	0.95
3	Thiel's inequality Coefficient	0.08	0.09	0.06	0.08	0.09	0.05

CONCLUSIONS

In this study, we found that the Manning values around the coast of Carey Island are between 35 and 45 $m^{1/3}/s$ according to water depths between 0 and 60 m. Based on the simulation results, it can be seen that the current speeds at the coast of Carey Island between 23th December 2014 and 7th January 2015 are less than 0.64.

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