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A Numerical Model of Seawater Volume and Velocity Dynamic for Marine Currents Power Plant in the Bangka Strait, North Sulawesi, Indonesia

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Abstract. One of equipment as prime movers in the marine current power plant is turbine. Marine current turbines require a data of marine currents velocity in its design. The objective of this study was to get the velocities distribution of marine currents in the Bangka strait. The method used survey, observation, and measurement in the Bangka strait. The data of seawater density conducted measurement in the Bangka strait. The data of width and depth of the strait collected from the map of Bangka strait and its depth of the sea. Problem solving of the study used a numerical model. The velocities distribution of marine current obtained from a numerical model in the form of numerical program. The results showed that the velocities distribution at seawater column when low and high tide currents which the maximum happened at 0.1 Sv were 0-0.9 and 0-1.0 m/s respectively, while at 0.3 Sv were 0-2.7 and 0-3.0 m/s respectively. The results will be a product in analyzing the potential kinetic energy that used to design profile of the turbines as prime mover for marine currents power plant in the Bangka strait, North Sulawesi, Indonesia.

1. Introduction

The Indonesian government through the President and Vice President seriously encourage increased electricity infrastructure in Indonesia [1]. It implemented with the issuance of Presidential Decree (Decree) No. 4 2016 on accelerating the development of electricity infrastructure. Earlier, the President had inaugurated the 35 thousand MW to Indonesia. Ministry Coordinator (CMEA) of Economic Affairs conducts socialization on follow-up to Presidential Decree no. 4 2016. The socialization intended to provide insight for agencies, as well as follow the implementation of efforts to accelerate the development of electricity infrastructure with emphasis on the use of New and Renewable Energy (EBT) to support efforts to reduce greenhouse gas emissions.

A numerical model to determine the velocity distribution of of marine currents in some areas in Indonesia has conducted by the Indonesian Hydrodynamics Laboratory BPPT and The Society of Naval Architects of Japan [2]. Similarly, Rompas and Manongko [3] have done it in the study on the distributions of marine current velocity in the Strait of Bunaken, North Sulawesi, Indonesia.

One component of marine current electricity power plant is the turbine. Making the turbine was badly in need marine current velocity data. It obtained by a study on numerical model of seawater volume and velocity dynamics.

The objective of this study was to get the velocities distribution of marine current in the Bangka strait, North Sulawesi, Indonesia by a numerical model.

2. Governing Equations

Fundamental mathematics equation that used in the numerical model is the conservation of energy equation. It would express the variations in temperature, especially in account dissipation by friction, will ignore and temperature will later appear as a tracer only liable for the effects of buoyancy. Conservative of the fluid mass based on the following equation [4]

$$\frac{\partial(\vec{U})}{\partial t} + \vec{U}\nabla\vec{U}) = \frac{1}{\rho}\, div\,(\underline{\sigma}) + \vec{g} + \vec{F} \qquad (1)$$

where ρ be the density of the fluid, and $\vec{U}$ the velocity vector, whose components are U, V, W. ∇ is the tensor operator "nabla". $\vec{g} + \vec{F}$ is external forces where g is the constant gravitational acceleration and the other forces (Coriolis acceleration, etc.)

In this study, based on the decomposition of preceding Reynolds and under the assumptions of hydrostatic pressure, then conservative of the fluid mass become Realized Average Navier-Stokes (RANS) equations [5]. The RANS equations were as a basic for the formulation of numerical model.

2.1. The boundary condition.

The domain of the Bangka strait is more complex of forms to free surface flows. Therefore, it needs limited. Some types of boundary conditions are required such as the boundary conditions at the bottom, the surface of the water, the wall, and open boundary. The first, at the bottom only horizontal velocity that could considered with used a Chezy formula [6]. At the surface, we used principally two conditions, the first is wind shear stresses in x-direction and the second is wind shear stresses in y-direction [7]. At the wall, we used the impermeable condition [4]. Finally, a condition of radiation and adaptive boundary condition that developed by Treguier *et al*. [8] used at open boundary.

2.2. The turbulence model.

The turbulent model for 2D used dept-average formulation from Stansby [9] as defined follow:

$$\nu_t = \left(l_h^4 \left[2\left(\frac{\partial \bar{u}}{\partial x}\right)^2 + 2\left(\frac{\partial \bar{v}}{\partial y}\right)^2 + \left(\frac{\partial \bar{v}}{\partial x} + \frac{\partial \bar{u}}{\partial y}\right)^2 \right] + (\gamma \bar{u}_f h)^2 \right)^{1/2} \qquad (2)$$

where the friction velocity $\bar{u}_f = \sqrt{|\tau_b| / \rho}$ with ρ is water density and bed shear stress $\tau_b = \sqrt{\tau_{bx}^2 + \tau_{by}^2}$ where $(\tau_{bx}, \tau_{by}) = C_f\, \rho(\bar{u}, \bar{v})\sqrt{\bar{u}^2 + \bar{v}^2}$ with $C_f = 0.0559\, \mathrm{Re}_h^{-0.25}$ is friction coefficient of the Blasius formula where the depth Reynolds number $\mathrm{Re}_h = (\sqrt{\bar{u}^2 + \bar{v}^2})h/\nu$, and γ is the Elder constant about 0.067 which are the depth-averaged vertical mixing, and the horizontal mixing length $l_h = \beta\lambda h$ where λ is a boundary layer constant (λ=0.09), h is water depth and $\beta = l_h/l_v$ is the constant from result comparison with experiment.

3. Numerical Approach

The numerical equations that used in this study were results developing from mathematical equations. Also, from the results of modification of the YAXUM/3D model that used by Ramirez *et al*. [10]. In the numerical model, we used semi-implicit finite difference method for the numerical solution of the three-dimensional Equation 1 in the computation of shallow water flows [6].

The velocities in x, y, and z directions, we used the equations which a general semi-implicit discretization of the momentum equations and we can written in the more compact matrix form as [6]

$$\mathbf{A}^{n}_{i+1/2,j}\mathbf{U}^{n+1}_{i+1/2,j} = \mathbf{G}^{n}_{i+1/2,j} - g\frac{\Delta t}{\Delta x}\left(\eta^{n+1}_{i+1,j} - \eta^{n+1}_{i,j}\right)\mathbf{\Delta Z}^{n}_{i+1/2,j} \qquad (3)$$

$$\mathbf{A}^{n}_{i,j+1/2}\mathbf{V}^{n+1}_{i,j+1/2} = \mathbf{G}^{n}_{i,j+1/2} - g\frac{\Delta t}{\Delta y}\left(\eta^{n+1}_{i,j+1} - \eta^{n+1}_{i,j}\right)\mathbf{\Delta Z}^{n}_{i,j+1/2} \qquad (4)$$

4. Method

4.1. The domain presentation of study

The geographical location of the Bangka Strait is from 125 ° 04'40 "E to 125 ° 11'18" E and from 1 ° 41'25 "N to 1 ° 44'03" N which consist of islands of Talise, Kinabuhutan, Ganges, Tindila, Lehaga, and Sulawesi. In the east, there are the Maluku Sea and Pacific oceans, and to the west is the Sulawesi Sea (see figure 1). In addition, there are two of the current circulations in the Bangka strait i.e. low tide currents and high tide currents.

Figure 1. Location of numerical study (Bangka strait, North Sulawesi, Indonesia)

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4.2. Methods of study

The methods used survey, observation, and measurement in the Bangka strait. The data of seawater density conducted measurement in the Bangka strait. The data of width and depth in the strait collected from the map of Bangka strait and its depth of the sea. Problem solving of the study used a numerical model. The solution of a numerical model we take the case in the Bangka strait for calculating the velocities of $\overline{u}$, $\overline{v}$ and $\overline{w}$ respectively, we can explain step by step as the first is the beginning of computation with start. Then, the read data that using the all of parameters in the numerical equations and time of calculating until time maximum for doing iteration. Next step, generation of the mesh such as horizontal and vertical meshes and then continue to the process generating the index such as generate the layers of vertical axis (depth) and boundary layers. The next process, it makes the initial conditions of velocities and seawater surface elevation. Then, step in the start of iteration process until maximum iteration that the beginning with the process of boundary conditions in the Bangka strait. Next, calculate advections in $\overline{u}$ and $\overline{v}$, which are the processes for calculating advections of horizontal velocities. Then, calculate surface elevations with a linear five-diagonal system. The next calculation is the calculation process of velocities in horizontal direction. Finally, the process to execute determination when the iteration has been greater than maximum iteration, if no then process will be continue to calculate again, and if yes then calculation to finish.

Table 1. Numerical Parameter for 2D-Simulations

Parameter	Value	Parameter	Value
g	9.81 m s^{-2}	$\rho_{seawater}$	1024 kg/m^3
Cz	48	Δx	60 m
τ_o	2 days	Δy	60 m
τ_i	1 day	Δt	1 sec
discharge	variable		

In table 1, there are two discharges that calculated with classifications are 0.1 Sv and 0.3 Sv. τ_o and τ_i are relaxation timescales at outflow and inflow conditions respectively [8]. Cz is Chezy coefficient and $\rho_{seawater}$ is density of seawater. Δx, Δy, and Δt are space step in x direction, space step in y direction, and time step respectively.

5. Results and Discussion

Figure 2-5 showed the result of modelling and numerical simulation. We can see that in the forms of simulations i.e. 2D-simulations when low tide currents and high tide currents. Figure 2 shows distributions of velocities and current threads at seawater column when low tide currents. Generally, seawater enters from section A and B where current flows from section A and go to section D and a small part flow to section C which previous rotate form two eddies like elliptic diameter at centre between Gangga and Bangka Islands. On the other side, current enter in section B flow to section C which previous form eddy in north area near Talise Island and a small part flow to section D which previous form small maelstrom like diameter between Gangga and Bangka islands. On the contrary, when high tide current (see Figure 3), current enters from section D go to section A and a small part flow to section B which previous happened eddy at center east area near Bangka Island whereas current from section C go to section B which previous form eddy like elliptic diameter at north area near Talise Island and a small part of the other current go to south side of Gangga Island at section A.

We can see in figure 4 which maximal velocities predominated at around section A when low and high tide currents at 0.3 Sv of 1.5-2.7 m/s (figure 4.b) and 1.2-3.0 m/s (figure 5.b) respectively. When high tide currents, the volume of seawater passing through the area was so large which is the result of a combination of direction section A and D (see also figure 3). Whereas when low tide current (see bottom centre area in figure 4), it was the depth that only of 5 m. The values shown that currents flow when high tide currents greater when low tide currents. Figure 5 shows distribution of marine current velocities at seawater column at discharges of 0.1 and 0.3 Sv respectively when high tide currents. The currents were so strong in the top of section C by 3 m/s. It is because not only so large volumes of seawater but also shallow sea of 6 m. In the centre of area, we can see that the average of marine currents velocity by 2.7 m/s.

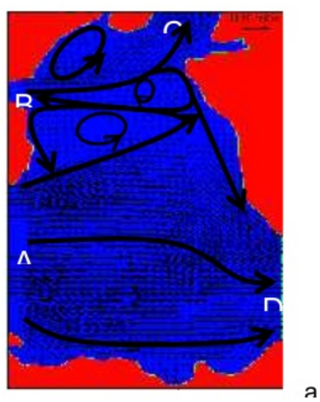


Figure 2. Simulations (2D) of marine current velocities and current threads at seawater column when low tide currents at discharges of 0.1 Sv (a) and 0.3 Sv (b)

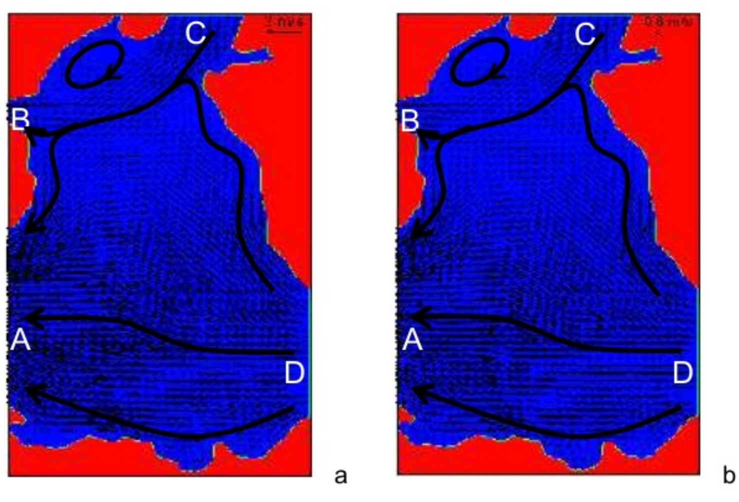
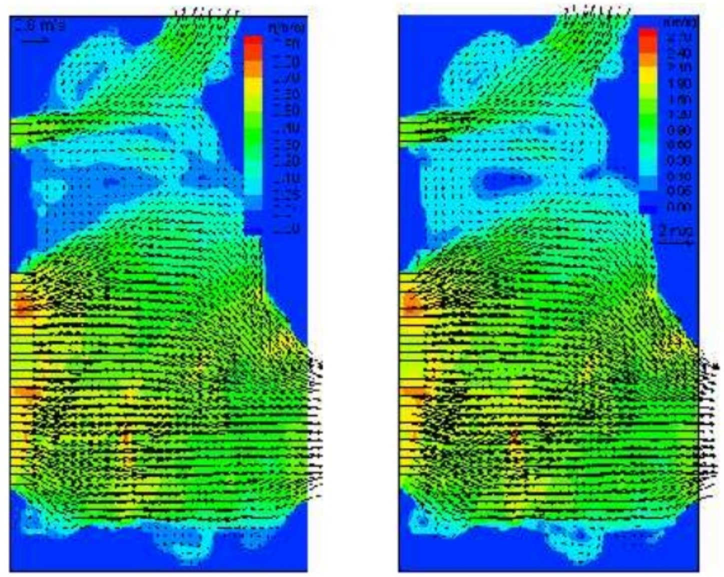
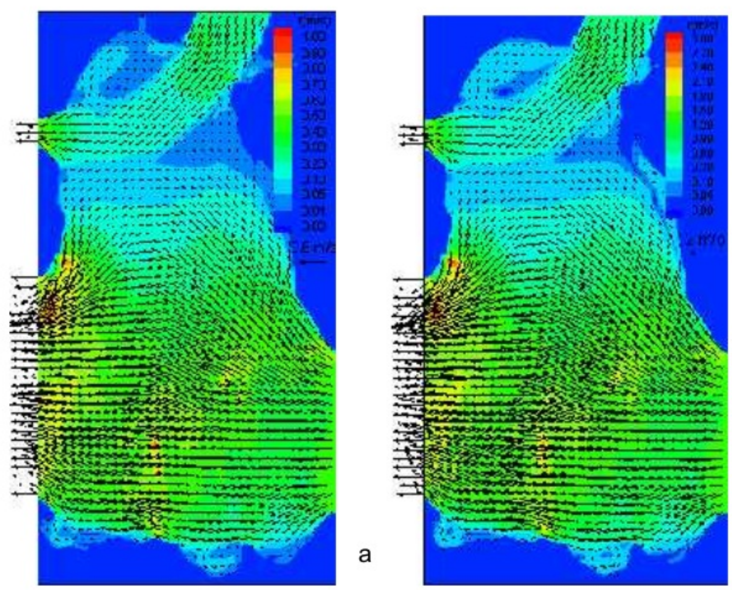


Figure 3. Simulations (2D) of marine current velocities and current threads at seawater column when high tide currents at discharges of 0.1 Sv (a) and 0.3 Sv (b)



a b

Figure 4. Distribution of marine current velocities at seawater column when low tide currents at discharges of 0.1 Sv (a) and 0.3 Sv (b)



a b

Figure 5. Distribution of marine current velocities at seawater column when high tide currents at discharges of 0.1 Sv (a) and 0.3 Sv (b)

The results in the figures 4 and 5 especially in the centre area of strait that the values of velocity can be used to design profile of the marine current turbine. Besides, this area is suited installed turbines for power plant which the ideal locations for power plant installation of the current energy have velocities of current two directions (minimum bidirectional) of 2.5 m/s or more, one way is minimum 1.2-1.5 m/s. The deepness not less than 15 m and the most at 50 m, the construction near the beach so that energy can be supplied at low cost, the area is spacious enough for more than one turbine installation, and no the area of sea transport and fishing [11].

6. Conclusions

We successfully obtained the velocities distribution of marine currents at seawater column in the Bangka strait, North Sulawesi, Indonesia by the numerical model. The velocities distribution at seawater column when low and high tide currents which the maximum happened at 0.1 Sv were 0-0.9 and 0-1.0 m/s respectively, while at 0.3 Sv were 0-2.7 and 0-3.0 m/s respectively. The results will be a product in analyzing the potential kinetic energy, which can used to design profile of turbines for marine currents power plant in the Bangka strait North Sulawesi, Indonesia.

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