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IDENTIFICATION OF POTENTIAL SITES FOR HARVESTING TIDAL CURRENT POWER IN KELIAN CAPE, KELABAT BAY, AND LARANTUKA STRAIT

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ABSTRACT: Harvesting of power from tidal currents is part of an emerging effort to capture energy from renewable sources, as non-renewable energy resources are depleted. The Indonesian government plans to develop tidal energy power generators in several areas and is conducting assessments in Bangka Belitung province at two locations in Kelian Cape and Kelabat Bay and in the province of East Nusa Tenggara at Larantuka Strait. Three potential locations namely Kelian Cape, Kelabat Bay, and Larantuka Strait, is assessed. Field measurements, numerical modeling, and potential site analysis are carried out. Both tidal elevation and tidal current validation between field measurement data and numerical modeling results are carried out and show good agreement. MIKE 3 (licensed) is used for the modeling process The Kelian Cape model presents three potential sites at Kelian Cape, with a peak velocity of 1.4 m/s. The Kelabat Bay model gives five potential sites, located at the bay's narrowest point, with a peak velocity of 1.15 m/s. The Larantuka Strait model gives four potential sites in the narrowest area, with a peak velocity of 2.5 m/s. Larantuka Strait is found to have the most potential for the harvesting of tidal current power, as the current velocity at Larantuka Strait is higher, meaning that turbine devices with higher cut-in speeds are suitable. In Kelian Cape and Kelabat Bay, devices with low cut-in speed such as the Gorlov Helical Turbine or Sabella Turbine are required.

Keywords: Tidal current power harvesting, Numerical modeling, Indonesia.

1. INTRODUCTION

Indonesian energy production is still dominated by non-renewable energy sources, which contribute greatly to emissions of global greenhouse gases (GHG) [1]. To reduce GHG emissions, which lead to climate change, the utilization of renewable energy sources is urgent. One of the best solutions for Indonesia is ocean-based renewable energy.

The ocean covers 75% of Indonesia's region and therefore the nation's engineers face considerable challenges in discovering potential sites to harvest energy. Wave, tidal, and thermal-based energy sources have been explored with various degrees of success. Recent studies on the wave, tidal, and ocean thermal-based energy harvesting show power potencies of 1,995, 17,989, and 41,001 MW, respectively [2]. The most reliable ocean-based renewable energy resource in Indonesia at this time is tidal current energy; wave-based energy gives a significantly lower harvest, and ocean thermal energy is constrained by a lack of ready technology.

Studies on harvesting power from tidal currents have been conducted around the world on topics from device design [3–4] to the potential location of a specific region [5–11]. Recent studies of potential power harvesting locations in Indonesia show 11 potential locations: Malacca Strait, Bangka Strait, Sunda Strait, and some waters around East Java, Bali, East Nusa Tenggara, West Nusa Tenggara, and West Papua [2, 7].

The Indonesian government plans to develop tidal energy power generators in several areas and is doing an assessment in Province of Bangka Belitung Islands at two locations in Kelian Cape and Kelabat Bay and in the Province of East Nusa Tenggara at Larantuka Strait. The tidal current power potency in those three locations, namely Kelian Cape, Kelabat Bay, and Larantuka Strait, is assessed.

The objective of the current study is to simulate tidal flow in Kelian Cape, Kelabat Bay, and Larantuka Strait. The study is designed to find the potential location with the highest tidal current velocity in order to harvest the most energy.

2. METHODOLOGY

2.1 Study Locations

This study takes place at three separate locations: Kelian Cape, Kelabat Bay, and Larantuka Strait. Fig.1 presents the observed locations. Bangka Strait is located between Sumatera Island and Bangka Island in the province of Bangka Belitung Islands, as shown in Fig.1(b). The locations of Kelian Cape and Kelabat Bay are at the northern inlet of Bangka Strait (see Fig.1(b)). Larantuka Strait separates Flores Island and Adonara Island in the province of East Nusa Tenggara, as shown in Fig.1(d).

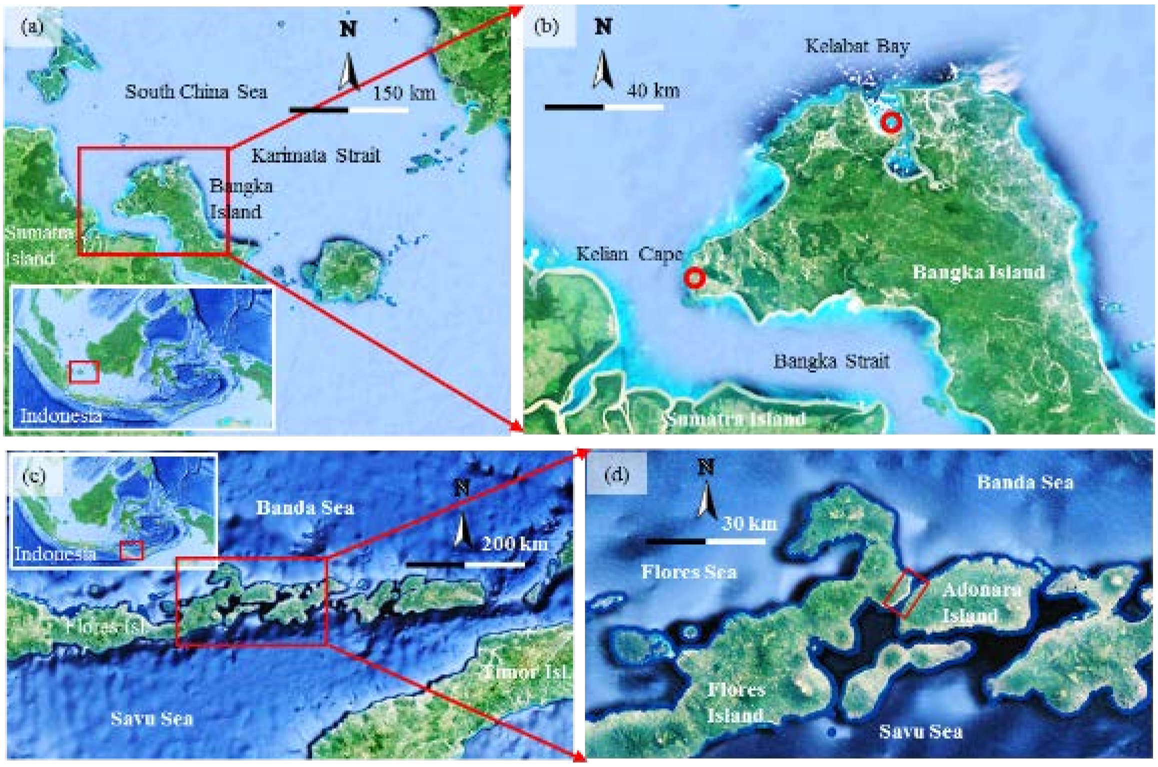

Fig.1 Locations of (a) Bangka Island, (b) North inlet of Bangka Strait, (c) Flores and Adonara Island (red box) in East Nusa Tenggara Province, and (d) Larantuka Strait

The strait width varies from 13 to 40 km. The area of interest in Bangka Strait is located in the north part of Bangka Island, notably around the coastal zone of Kelian Cape and Kelabat Bay (see the areas marked with red dots in Fig.1(b)).

Tidal characteristics in Kelian Cape and Kelabat Bay are found to be mixed: mainly semidiurnal with a tidal range of 2.8 m [12] and diurnal with a tidal range of 1.7 m [13]. There are three tidal current velocity measurement stations along Bangka Strait, which show 1 m/s as the maximum current velocity [14]. However, the current at Kelian Cape and Kelabat Bay are anticipated to be higher since the flow is turning and tapering, which increases the velocity.

The locations of West and East Nusa Tenggara province are given in Fig. 1(c). Larantuka Strait is located between Flores and Adonara Island, connecting Savu and the Banda Sea as given in Fig.1(d) with a red box. Larantuka Strait has 8 km long and 4.5 km wide at both inlets. At the narrowest point, the strait is approximately 600 m wide and 20 m deep. The tidal flow is expected to be high due to significantly narrowing channel. Orhan et al. (2015) showed that the tidal range and tidal current peak velocity are approximately 1.5 m and 3–4 m/s [8].

2.2 Field Measurements

Field measurement is carried out to determine the bathymetry, tidal elevation and current at the area of interest. The bathymetric survey used a single beam echosounder and processed to result in a detailed base map. The tidal elevation was recorded hourly by an Automatic Water Level Recorder (AWLR) installed on a local jetty for a half-moon cycle (15 days).

An Argonaut-XR type Acoustic Doppler Current Profiler (ADCP) was used to record the current velocity magnitude and direction. The ADCP is placed above the seabed, 20 m below the water level. The velocities are collected with 10 layers data for 3D model validation. Fig.2 shows the configuration of the measurement layers.

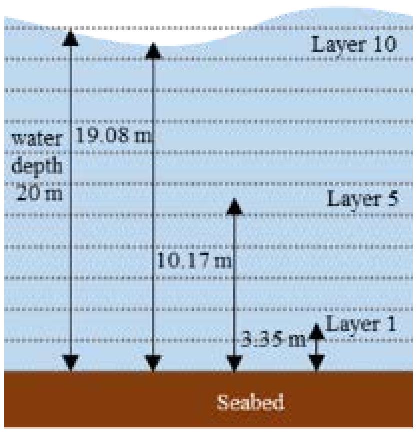

Fig.2 Illustration of positions of ADCP layers

2.2.1 Kelian Cape, Bangka Strait, Province of Bangka Belitung Islands

The base map obtained from the bathymetric survey covers area described by a transparent yellow area around Kelian Cape as seen in Fig.3(a). The deepest point was found to be 50 m. The location of the tidal elevation survey is shown in Fig.3(a) as point BT1 carried out from December 14^{th,} 2013 to January 4^{th,} 2014. The tidal range is 2.5 m (mixed, mainly diurnal type).

The tidal current survey was conducted at site BC1 in Fig.3(a) from November 6th to 12th 2013. The measured tidal current ranged from 1.0 to 106.1 cm/s. The slowest and fastest tidal current are located around 3m above the seabed and in the mid-depth of around 10m above the seabed, respectively. The tidal current velocity direction is dominantly eastward during the flood to ebb tide and westward during ebb to flood tide.

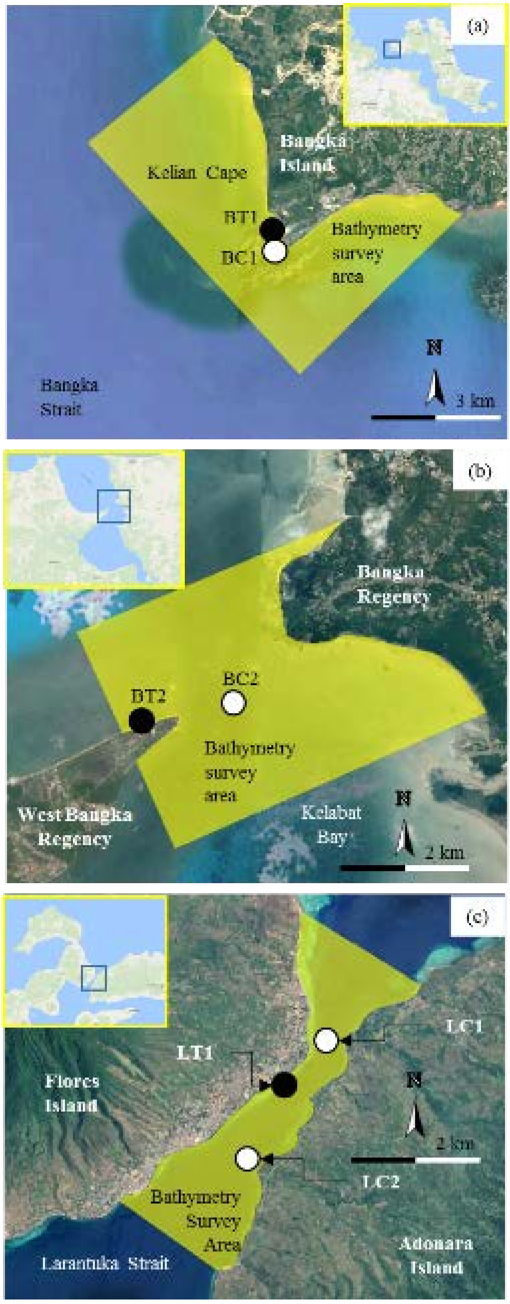

Fig.3 Survey location at (a) Kelian Cape, (b) Kelabat Bay, and (c) Larantuka Strait

2.2.2 Kelabat Bay, Province of Bangka Belitung Islands

The bathymetric survey area for Kelabat Bay can be seen in Fig.3(b), marked by the transparent yellow block. The deepest point is 28 m. The tidal elevation was measured from December 21st 2013 to January 4th 2014 at point BT2. The tidal range was found to be 2.1 m (diurnal type).

The tidal current was measured at BC2 from October 30th 2013 to November 5th 2013, where the velocity varied from 0.1 to 102.4 cm/s. The smallest and peak tidal current was found at the bottom and top layers, respectively. The tidal current velocity direction is dominant to the southeast during the flood to ebb tide and the opposite during ebb to flood tide.

2.2.3 Larantuka Strait, Province of Nusa Tenggara Timur (NTT)

Fig.3(c) shows the bathymetric survey area in Larantuka Straits. The deepest point was found to be 75 m. The tidal elevation survey was carried out at Paloh Beach (see LT1 in Fig.3(c)) from November 21st 2013 to December 4th 2013. The tidal analysis shows a tidal range of 2.6 m with mixed, mainly semidiurnal tide type.

The tidal current velocity was measured at points LC1 (November 14th to 20th 2013) and LC2 (November 22nd to 27th 2013) in Fig.3(c). The measured tidal current velocity ranges from 0 to 286 cm/s at LC1 and from 0.4 to 194.3 cm/s at LC2. The tidal current velocity is predominantly directed to the northwest during the flood to ebb tide and southeast during ebb to flood tide.

2.3 Model Setup

MIKE 3 is used for hydrodynamic numerical modeling to simulate the velocity distribution around each area in order to select the best locations for tidal current power harvesting induced by the tide. Similar studies have been conducted using other software, such as Delft3D [9], Telemac [15], ROMS [10], FVCOM [4], and MIKE [16]. The current study uses MIKE 3 (personal license).

The numerical model is divided into two steps, the global and local model. The global modeling is carried out to generate the valid tidal current particularly around the local model which going to be constructed into local model boundary conditions. The resulted current velocities obtained from the global model will become boundary conditions in the local model, which has more detailed mesh around the area of interest. The model is run in 10 layers, corresponding to the 10 layers of ADCP field measurement.

2.3.1 Potential Locations in the Province of Bangka Belitung

There are two potential locations in Bangka Belitung Province: the areas around Kelian Cape at Bangka Strait (see Fig.1(b)) and Kelabat Bay (see Fig.1(b)). The global model for both areas, shown in Fig.4, covers Bangka Strait and Karimata Strait (see Fig.1(a)).

There are two local models to simulate the tide-induced current velocity distribution around Kelian Cape and Kelabat Bay. The first local model is of Kelian Cape, as shown in Fig.5(a). The second local model is of Kelabat Bay, as shown in Fig.5(b).

2.3.2 Larantuka Strait

The global model, given in Fig.6, is covering East Nusa Tenggara Province and the seas surrounding. While as presented in Fig.7, local model domain is located at Larantuka Strait (see the red box in Fig.1(d)).

The mesh size is ranged from 2 km at boundaries and 200 m at interest area for the global model. In the local model, they are 1 km and 40 m. For both models, the mesh becomes finer from the boundary to the area of interest.

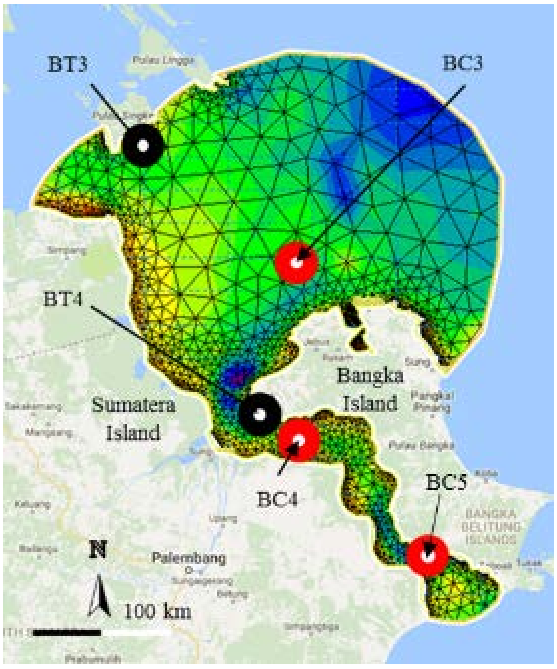

Fig.4 Domain of Bangka Strait (Kelian Cape and Kelabat Bay) global model

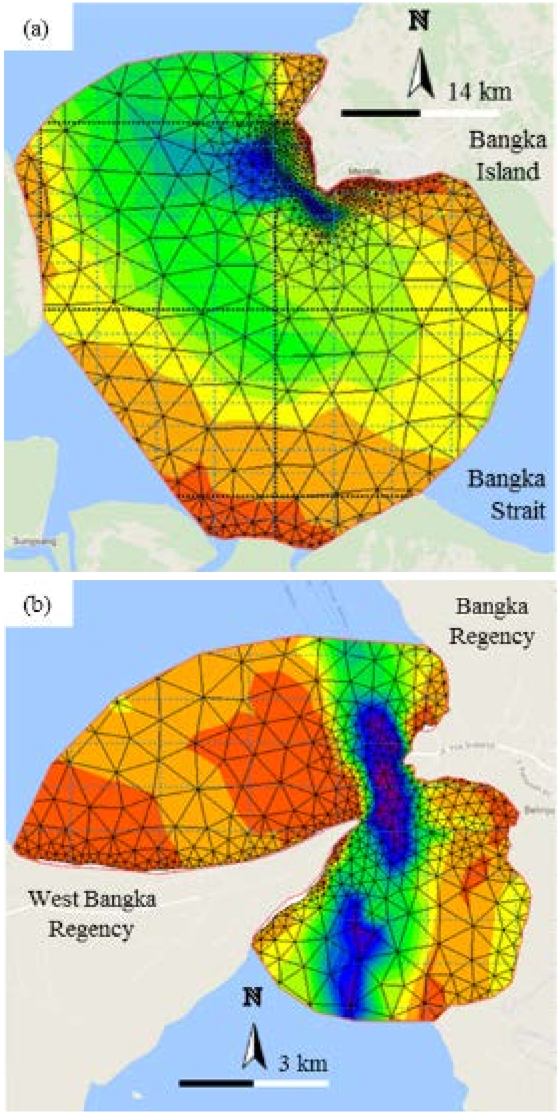

Fig.5 Domain of (a) Kelian Cape and (b) Kelabat Bay local model

3. RESULTS AND DISCUSSION

The results of both models present three stages for each location: tidal elevation validation, tidal current validation, and potential site analysis. The model result and field data were compared to obtain the model validity.

For validation of the model data, an error α is introduced in Eq. (1). The validated parameters are the sea surface elevation and current velocity [11–14].

$$\alpha = \frac{|\mu_m - \mu_f|}{\lambda} \quad (1)$$

where the model result denoted as μ_m, field data denoted as μ_f, and tidal range denoted as λ. The μ can be the sea surface elevation or current velocity magnitude.

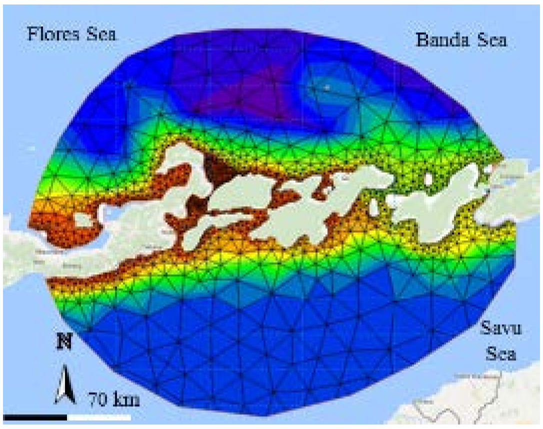

Fig.6 Domain of Larantuka Strait global model

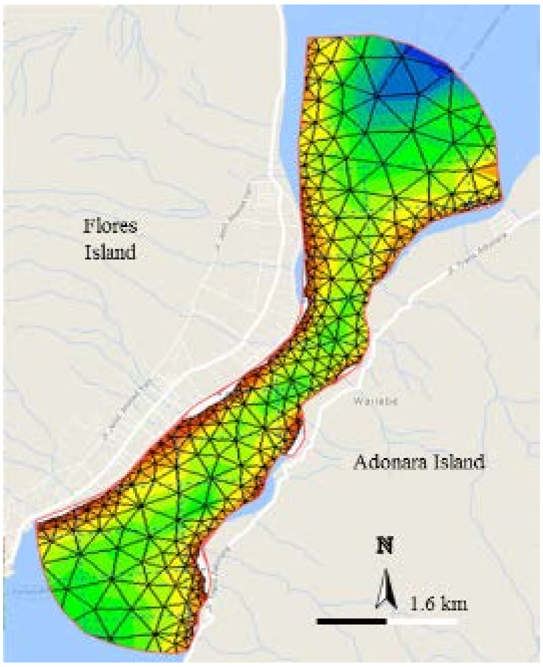

Fig.7 Domain of Larantuka Strait local model.

3.1 Bangka Strait Model Analysis

3.1.1 Tidal Elevation Validation

Tidal elevation validation is conducted for the Bangka Strait global model and the Kelian and Kelabat local models. The compared tidal elevation data for the global model are obtained from the Indonesian Navy Tidal Database at Dabo Singkep (BT3) and Muntok Station (BT4) (see Fig.4), which give 4.5% average error as shown in Figs.8(a) and 8(b) [12].

The compared tidal elevation data for the local models are obtained from field measurements. The results of these validations give 6.2% average error for the Kelian Cape model at BT1 (Fig.8(c)) and 7.14% for Kelabat Bay local model at BT2 (Fig.8(d)), both show good agreement.

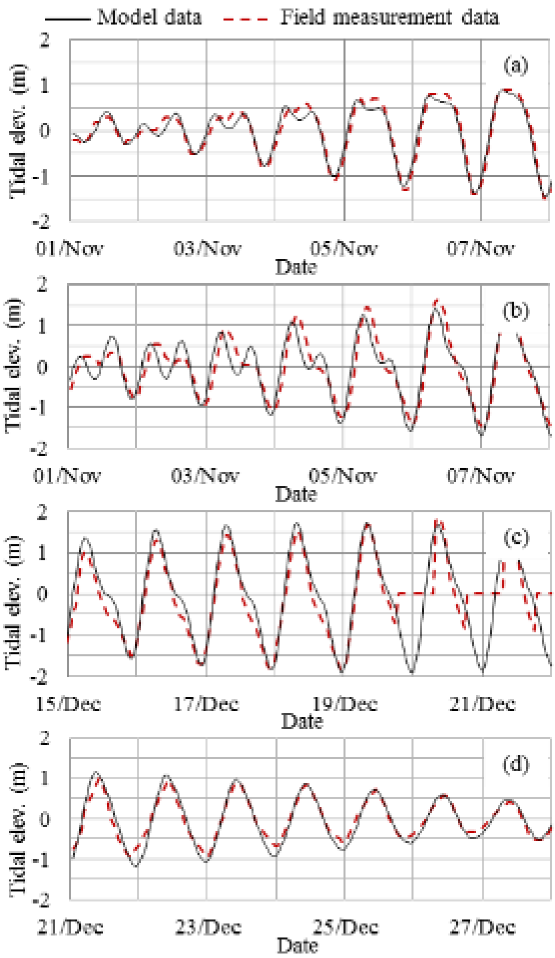

Fig.8 Validation of tidal elevation in Bangka Strait (both global and local model) at (a) Dabo Singkep (BT3), (b) Muntok Station (BT4), (c) Kelian Cape (BT1), and (d) Kelabat Bay (BT2).

3.1.2 Tidal Current Validation

The locations of validation for the Kelian Cape model are BC3, BC4, and BC5, which are obtained from the measurement stations of Indonesian Navy Tide Table (see Fig.4).The stations are located at Tujuh Island (BC3), Amelia Shoal (BC4), and Nemesis Shoal (BC5). Since the data measured by the Indonesian Navy are a surface velocity, the data are compared to data at the uppermost layer of the model. Using Eq. (1), the error is found to be 8% (averaged value). Figs.9(a), 9(b), and 9(c) show the validation results for BC3, BC4, and BC5. The plots show good agreement.

The tidal current validation for the local model is carried out using field measurement data at location BC1 for the Kelian Cape local model and BC2 for the Kelabat Bay local model. The average errors α are 12.32 and 11.37% for the Kelian Cape and Kelabat Bay models, respectively (see Figs.10 and 11 for the scatter plot validations).

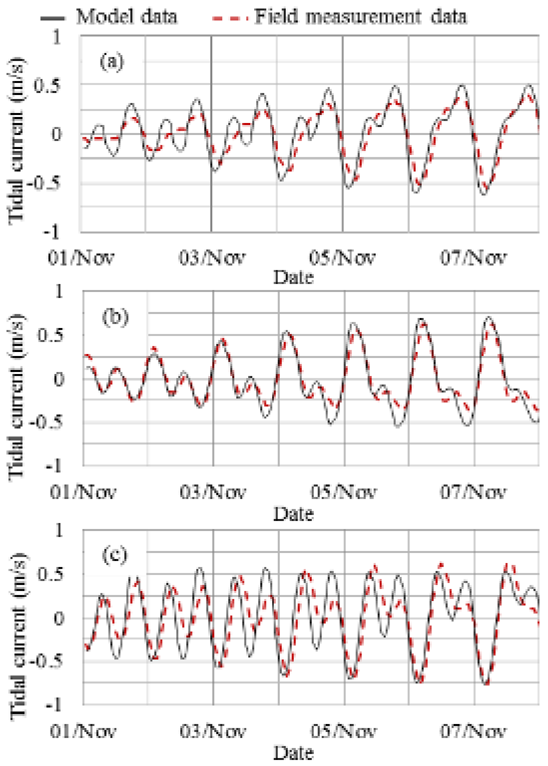

Fig.9 Validation of tidal current in Bangka Strait global model from November 1 to 7, 2013, at (a) Tujuh Island (BC3), (b) Amelia Shoal (BC4), and (c) Nemesis Shoal (BC5)

3.1.3 Potential Site Analysis

Locations for potential site analysis were taken from the local model domain. The analysis was conducted by comparing the velocity distribution at some points. There are three investigated potential sites in Bangka as given in Fig.12. The velocity at the three proposed sites shows that location 1 is the most site with the greatest potential since it has a maximum current velocity of 1 m/s as shown in Fig.13.

The same method was used for the Kelabat Bay local model analysis. The selected sites are given in Fig.14. From the four potential sites, site 6 presents the highest potential velocity, reaching 1.15 m/s, as shown in Fig.15.

3.2 Larantuka Strait Model Analysis

3.2.1 Tidal Elevation Validation

Tidal elevation was validated for the Larantuka Strait local model at site LT1 (Fig.7). The model result values were compared with hourly data from field survey for 14 days (given for 7 days in Fig.16). The validation showed 4.04% error and was considered to be a good validation.

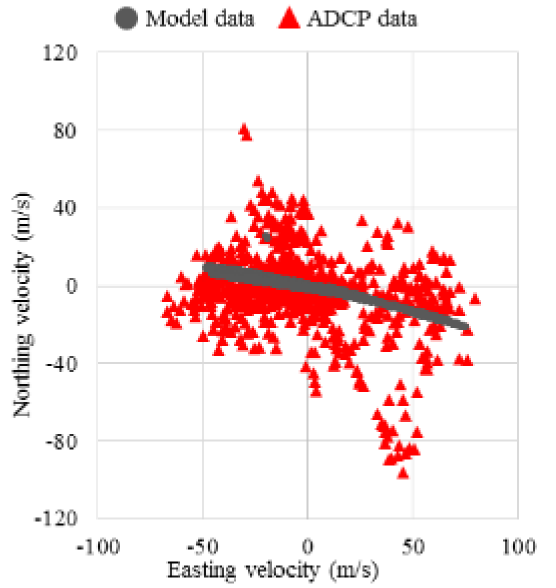

Fig.10 Validation of tidal current in Kelian Cape local model, BC1 from November 6th to 12th 2013.

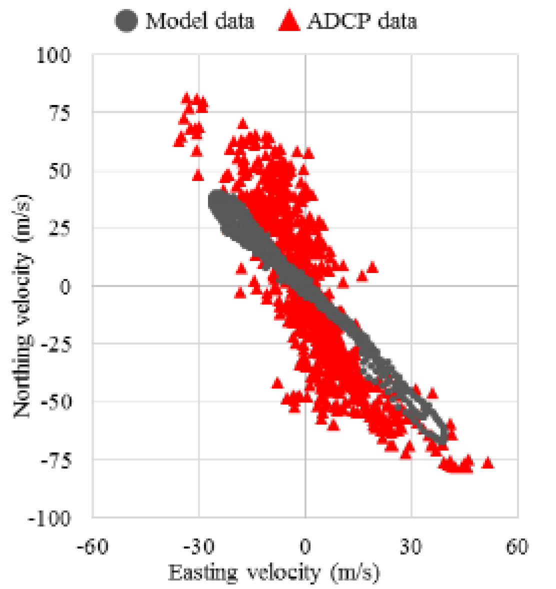

Fig.11 Validation of tidal current in Kelabat Bay local model, BC2 from October 30th 2013 to November 5th 2013.

3.2.2 Tidal Current Validation

The obtained field data at LC1 and LC2 (Fig.7) were compared with the Larantuka local model result to determine the tidal current validity. The average errors were 13.11 and 6.51% for LC1 and LC2 respectively (Fig.17 shows the scatter plot validations).

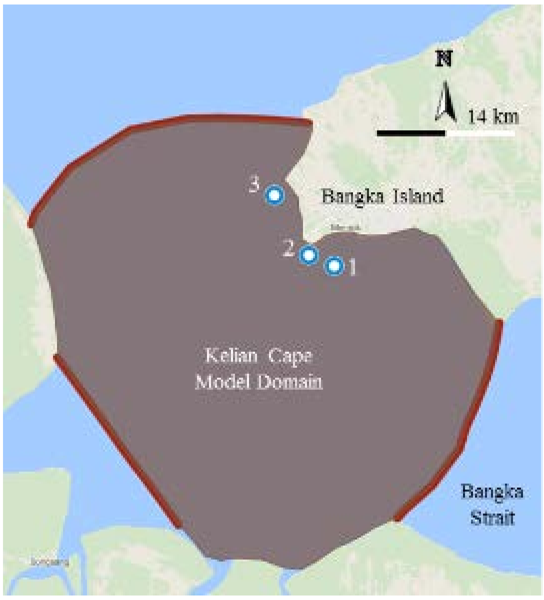

Fig.12 Investigated points (1 to 3) in the Kelian Cape model.

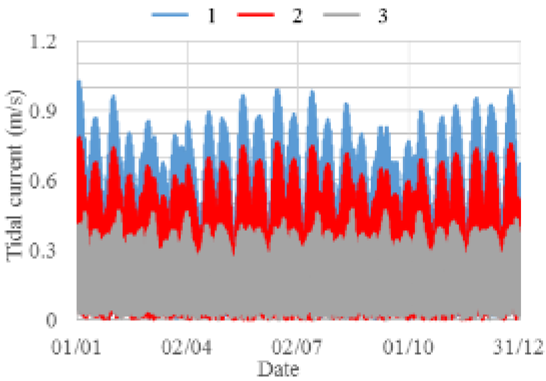

Fig.13 Tidal current of the investigated sites in Kelian Cape in 2014

3.2.3 Potential Site Analysis

The same potential site analysis method was carried out for Larantuka Strait. The investigated potential sites are presented in Fig.18. The velocity of the four proposed sites is presented in Fig.19. Site 9 is found to have the highest potency since the highest peak velocity is over 2.5 m/s.

3.3 Comparative View

Analysis of the three areas showed that the tidal current velocity in Larantuka Strait is higher than in both Kelian Cape and Kelabat Bay. The peak velocity in Larantuka Strait is around 2.5 m/s, almost twice that of the other areas. In Bangka Strait and Kelabat Bay, the maximum current velocities are 1 and 1.15 m/s. These three areas also suggest that the current intensifies due to the tapering of the flow channel.

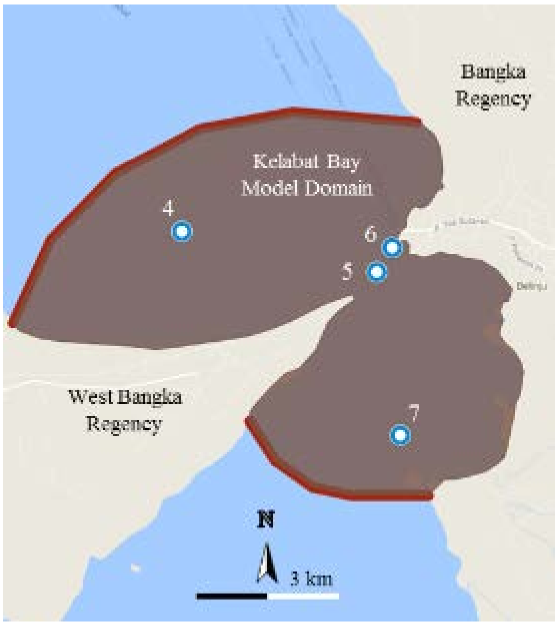

Fig.14 Investigated points (4 to 7) in Kelabat Bay model

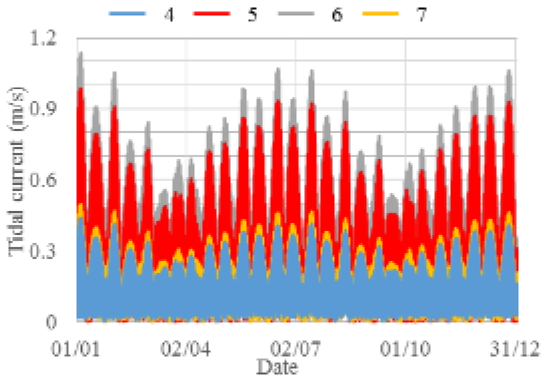

Fig.15 Tidal current of the investigated sites in Kelabat Bay in 2014

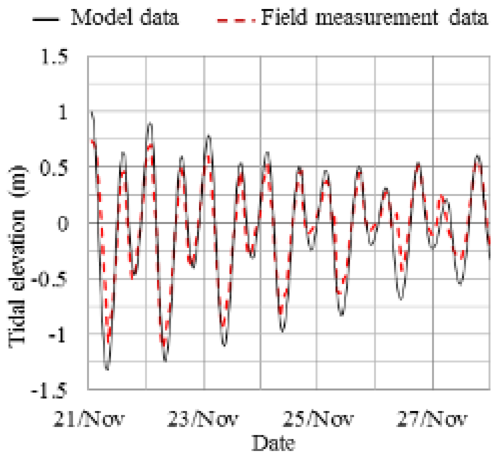

Fig.16 Validation of tidal elevation in Larantuka Strait, LT1

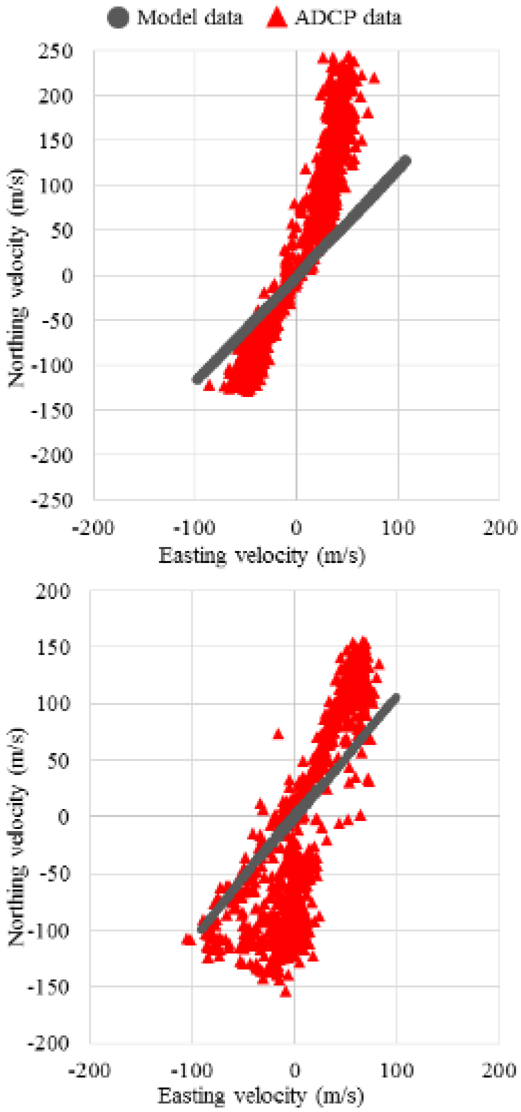

Fig.17 Validation of tidal current in Larantuka Strait local model from November 14th to 20th 2013 (upper figure) and November 22nd to 27th 2013 (lower figure).

4. CONCLUSION

Numerical hydrodynamic modeling was carried out at three potential locations for the harvesting of tidal-current energy. The modeling resulted in a good validation. The surface elevation errors (with tidal survey data) for Kelian Cape, Kelabat Bay, and Larantuka Strait are 6.2, 7.14, and 8%. The tidal current average errors are 12.32, 11.37, and 9.81%.

The potential site analysis in the three locations showed that the highest velocity is mostly found in the spring flood condition and located at the narrowest part of the channel.

It is found that the highest potential velocity is in Larantuka Strait and is around 2.5 m/s. The peak velocities for Bangka Strait and Kelabat Bay are about 1 and 1.15 m/s respectively.

Since the current velocity in Larantuka Strait is

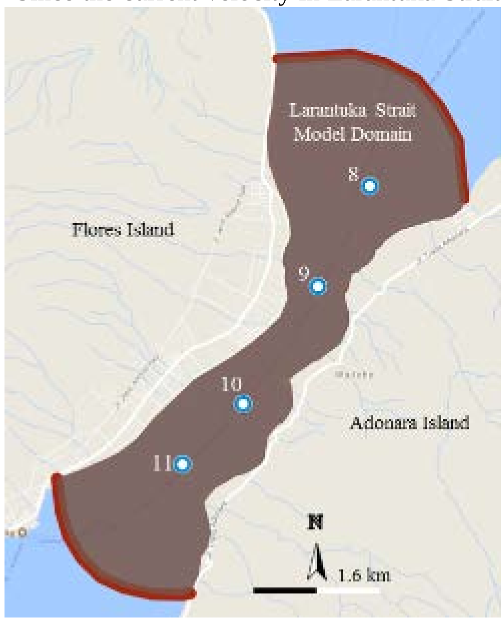

Fig.18 Investigated points (8 to 11) in the Larantuka Strait model.

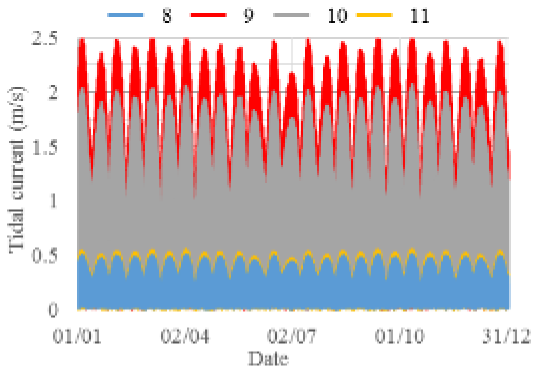

Fig.19 Tidal current of the investigated sites in Larantuka Strait in 2014

higher, there are more options for suitable devices that can be utilized to harness electricity. In Bangka Strait and Kelabat Bay, a device with a low cut-in speed is needed to accommodate the velocity characteristic. For example, the Gorlov Helical Turbine and Sabella Turbine have a cut-in speed of 0.5 m/s [3].

In the future, it is expected that ocean-based renewable energy in Indonesia will grow to solve the national energy security challenge. Thus, it is recommended that the practical, environmental, navigational, financial, and social feasibilities be studied further to provide a broader overview of the harvesting of tidal current power.

5. ACKNOWLEDGMENTS

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