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Analysis of Marine Current Turbine Placement Location in Suramadu Bridge - Indonesia

Ahmad Syafiul Mujahid,[a,*] Erwandi,[b]

[a)] *Research Engineer, Laboratory for Hydrodynamics Technology – Agency for Assessment and Application Technology, Indonesia*
[b)] *Sr. Research Engineer, Center of Technology for Maritime Industrial Engineering – Agency for Assessment and Application Technology , Indonesia*

*Corresponding author: ahmad.syafiul@bppt.go.id; ahmadsmujahid@gmail.com;

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ABSTRACT

Marine current turbine is a system of marine current power plant to produce renewable electrical energy derived from marine currents. After marine current turbine successfully tested in Larantuka Strait in 2010,, then in 2015 marine curent turbine team from BPPH-BPPT has conducted a study for placement of marine current turbine test that located in Suramadu Bridge, Madura Strait, East Java, Indonesia. This study uses survey data technique by direct measurement; Type of survey that is conducted using sampling technique by sampling method: purposive sampling or judgemental sampling. the subject of sampling data is marine current velocity data and ocean depth data which is chosen by researcher in the waters around the pile 56 to pile 57 under Suramadu Bridge. Measurements were conducted using instruments measurement: portable sounder, flow meter, and GPS. The measurement showed average depth: 11.4 meters and average marine current velocity: 1.3 m/s. By using the Betz Law Equation then the largest electric power can be obtained: 4.507 kW that located at 4.5 meters from pile 56 location. The Computational Fluid Dynamics (CFD) simulation is conducted to obtain the position of marine current turbine placement in order that turbine blades can rotate at optimum marine current speed. The optimum placement result of marine current turbine is located at 6.3 meters from piles 56 to the center of turbine, and the furthest distance from pile 56 to the turbine blade is 8.1 meters.

KEY WORDS: *Marine Current Turbine, Survey Data Analysis, Computational Fluid Dynamics*

NOMENCLATURE

P	Electric power generated [Watt]
0.348	Betz Law efficiency - obtained from real testing
ρ	Sea water density [kg/m^3]
A	Cross section area of turbine blade [m^2]
v	Marine current velocity [m/s]
Δh	Loss [m/s]
v_1	inflow current velocity [m/s]
v_2	outflow current velocity [m/s]
g	gravity [m/s^2]

1.0 INTRODUCTION

Marine current turbine is a system that can produce renewable electrical energy that comes from ocean currents. Marine currents are a source of renewable energy that is very potential to be developed in Indonesia as an archipelagic country.

Some study have been applied about the ocean current turbines in Indonesia, such as: Mahaganti et al. (2014) presented marine current power plant using asynchronous generator. Togan (2000) has studied The design of energy storage system by using battery on the marine current power plant at Ketapang Village, East Lombok district, NTB Province. Azis (2009) presented the advantage study of marine current electrical power plant at Alas Strait NTB.

In the research activities that have been conducted successfully at previous time by BPPT is Testing the prototype of marine current turbine on March 30th 2010 and June 2010 in Larantuka Strait - NTT by marine current turbine team from UPT. BPPH – BPPT Surabaya or Indonesian Hydrodynamics Laboratory, from the test result was obtained electrical power from the turbine with a capacity of 2 kW.

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Figure 1: Suramadu Bridge
(Source: https://www.pinterest.com)

In this study, the marine current turbine placement is conducted in different location, that is under |Suramadu Bridge, the bridge that crosses The Madura Strait, connecting Java Island and Madura Island. Potential of marine current energy resources around Suramadu Bridge location could be used as alternative renewable energy sources that finally can be used as electricity supplier in Suramadu Bridge, then it is necessary to conduct the survey for mapping the marine depth datas and marine current velocity datas on Madura Strait, furthermore is conducted the analysis of determining location for obtaining the right placement marine current turbine in order to optimum turbine rotation. The method in this study is presented on the flow chart that presented on Figure 2 following:

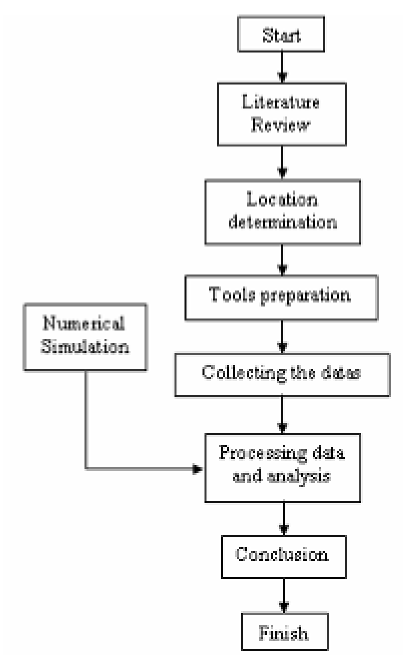

Figure 2: Steps of study

2.0 THEORY

2.1 Survey Technique

Survey is a main technique to collect the primary data when the secondary data is considered not complete enough to answer a question. On the study that using the survey method, surveyor only records the genuine data and then analyzing and interpreting that data to be concluded. Survey is used to measure the symptoms that exist without investigating why these symptoms happen. The main goal of the survey is to use obtained data to solve the problem [5].

Marine current energy is the kinetic energy that converted into electrical energy easily with high efficiency because water density is 830 times of the air density. The type of turbine that used under Suramadu bridge has decided back to the turbine blades as in Larantuka by types of Darrieus vertical axis turbines, straight-bladed turbine with a rotary diameter is 1.8 meters, blade length 2 meter, marine current flows bi-direction [6]. An ideal location for the installation of the marine current power plant (turbine) has a bi-directional flow speed at least 2 m/s, ideally 2.5 m/s or more. The depth not less than 15 meters and not more than 40 or 50 meters. Relatively close to the coast in order that energy can be supplied at low cost. Wide enough, and not cruise or fishing area [9].

The speed of marine currents in the Madura Strait is a typical speed of marine currents mostly straits in Indonesia [1]. The placement of the turbine location in the direction of marine currents is very important for turbine rotor speed. At the moment of the full moon or dead moon position then the current speed is very high, but in half moon position the flow rate is very small.

Figure 3: Marine current turbine system
(isometric view)

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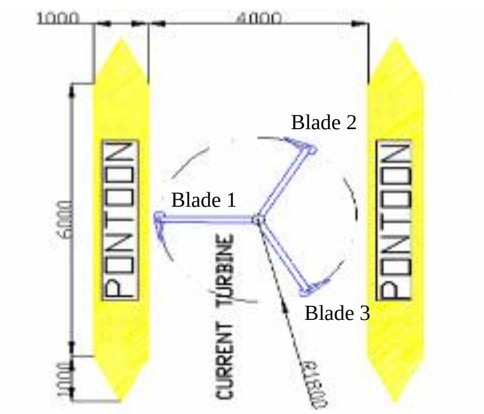

Figure 4: Principal dimension of marine current turbine in mm (top view)

2.2 Survey Methodology

This research uses survey techniques to obtain the marine current data; namely by direct measurement periodical or real time to obtain: marine current speed and direction, depth to the seabed, marine current direction and movement, visual observation of the marine current surface behavior and waves.

The survey was conducted using sampling techniques. The sampling technique in this research uses non-probability sampling technique that is discovered or determined by the researcher or by expert judgment. The type or sampling method is: purposive sampling or judgmental sampling, the sampling method was conducted by selecting the subject based on specific criteria that was defined researcher.

Survey location for collecting the data has been stipulated by researcher that is the waters between Pile 56 to Pile 57 under Suramadu Bridge. The reasons for selecting the survey location are as follows:

1. It is easier and cheaper when marine current turbine system installation will be conducted.
2. It has the potential of marine current speed sufficiently.
3. The possibility of the marine current flow would be faster because the bridge column on the pile 56 and pile 57 which indirectly can serve as a "ducted" that useful to focus the marine current flow and increases the velocity flow.
4. It is expected that later can be used to aid the Suramadu Bridge power needs.

The measurement equipments that used in this study are as follows:

1. **Speedtech SM-5A Depthmate Portable Sounder.**
   The portable water depth measuring devices with excellent quality that is easy to use and extremely accurate with depth measurement accuracy range: 2 to 260 feet (0.6 to 79 meter), having a good transmission transducer with high frequency: 200 kHz and beam angle value: 24^{o} thereby speeding up the reading data process, the tool has been designed to be used in water depth survey research. (see Figure 5).
2. **Flowatch FL03.**
   Flow Meter or Current Meter which is a tool to measure the water flow in accuracy: + / - 5% from -10^{o}C to + 50^{o}C and it has a measurement capability 2 to 150 km/hour. (see Figure 6).
3. **GARMIN GPSMAP 76CSx**
   GPS tool with high sensitivity and fast, having barometric altimeter and electronic compass, it is used in open space. (see Figure 7).
4. **Google Earth and Google Maps Software.**
   This software are used for aid or backup the survey location determination.

Figure 5: Speedtech SM-5A Depthmate Portable Sounder

Figure 6: Flowatch FL03

Figure 7: GARMIN GPSMAP 76CSx

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2.3 Electrical Power Calculation

Marine current turbine blade that used under Suramadu Bridge location using turbine blade type as in Larantuka location [2]. To determine the electric power generated by the marine current turbine can be calculated using the equation Betz Law:

$$P = 0.348 \cdot 0.5 \cdot \rho \cdot A \cdot v^3 \qquad \text{.................. (1)}$$

2.4 Numerical Analysis Method

To predict the optimal placement of turbines between pile foundation 56th to pile foundation 57th based on data referring to measurement data that has been carried out in the survey process, then numerical analysis methods are used in CFD-based computer simulations. CFD is defined as a calculation technique for predicting fluid flow phenomena using computer simulations, one of them is used in the hydrodynamics area. CFD is used in ship and marine area are mostly related to analysis of resistance and flow. CFD makes it possible to predict flow phenomena that are more complex with varying accuracy including pressure distribution along the object of research, prediction of viscosity resistance, flow visualization and analysis of the influence of free surfaces. CFD is able to provide better predictions about the level of interaction caused by the distribution of pressure and changes in frictional resistance along the object of research. CFD is still in good limits if the error margin compared with testing is not more than 5%. [12]

To obtain good CFD numerical simulation results, a validation process is needed. Many methods are carried out in validating numerical results, one of the methods used to validate is the experimental results. In this study, the measurement data result between the inflow (current-in) and the outflow (current-out) of the turbine are different where current velocity outflow was much smaller than the current velocity inflow, that poblem cause a loss effect. The results of the loss value between the speed of the inflow current and the outflow of the turbine from the survey data conducted at the location compared to the loss value on the CFD simulation. Calculation of loss value using the following equation:

$$\Delta h = \frac{(v_1 - v_2)^2}{2g} \qquad \text{.................. (1)}$$

While the CFD simulation results in the form of fluid flow patterns that flowing around the marine turbine current blade using the validation of the flow pattern that formed around the blade from the experimental results that have been carried out by Fujisawa and Shibuya (2011). In their research describes the fluid flow pattern around the Darreius blade, where marine current turbine uses Darrieus blade as well, that is schematic illustration as shown in Figure 8 and figure 9.

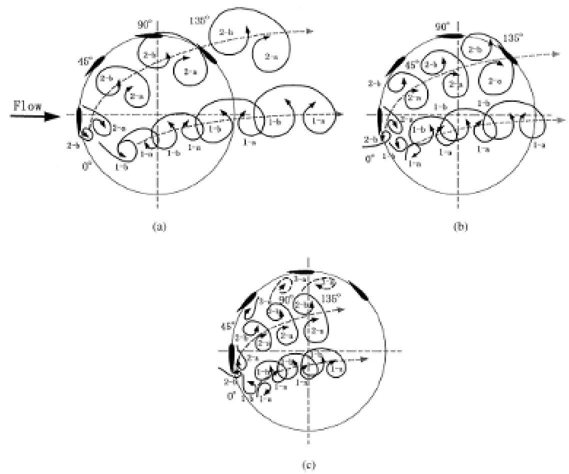

Figure 8: Schematic illustration of dynamic stall: (a) $\lambda = 1$, (b) $\lambda = 2$, (c) $\lambda = 3$. from Fujisawa and Shibuya (2011)

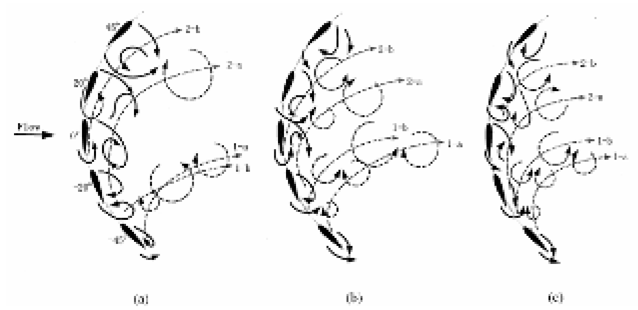

Figure 9: Close-up illustration of dynamic stall near blade:(a) $\lambda = 1$, (b) $\lambda = 2$, (c) $\lambda = 3$. from Fujisawa and Shibuya (2011)

3.0 RESULT AND DISCUSSION

After the measurement process is carried out at the research location as shown in Figure 10 then the measurement results of the average depth and current velocity have been obtained. Measurement results of average depth and current velocity with horizontal distance per meter from the location of pile foundation 56th to pile foundation 57th shown in graphical form in Figure 11. By using the equation (1), then the estimated electrical power produced by marine current can be calculated, graph of the effect of sea current velocity on electrical power is shown in Figure 10. Current velocity values that varies at 0 to 13 meters from the position of pile foundation 56th obtained a maximum current velocity value of 1.95 m/s which is located at the position of 4.5 meters from the position of pile foundation 56th. And the current velocity value at position 14 meters from foundation 56th to foundation 57th is equal to 1.1 m/s.

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Figure 10: Marine depth measurement process under Suramadu Bridge

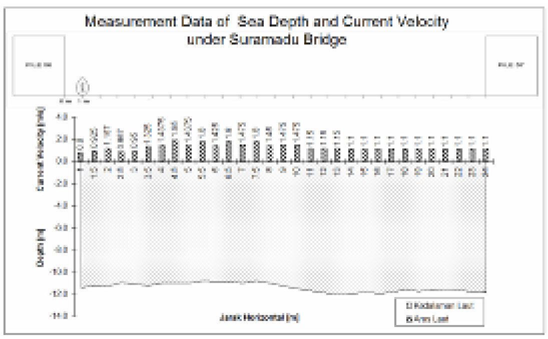

Figure 11: The result of measurement data

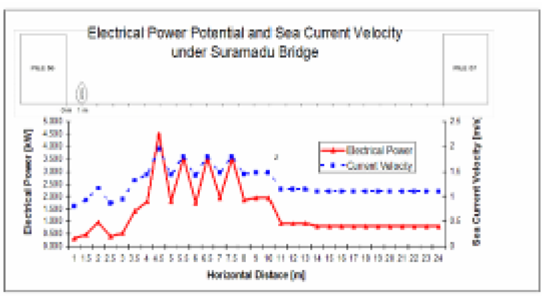

Figure 12: Cuurent Velocity and Potential Electrical Power under Suramadu Bridge

The Results of analysis at the research location indicate that the best access from land (Surabaya City) to these waters (Madura Strait under Suramadu Bridge) is in the location of the pile foundation 56th, so that the placement plan to install marine current turbines will be placed close to the pile foundation 56th. To obtain the best placement of the turbine so that obtained the maximum speed of the ocean currents then analysis of the placement location aided by numerical simulation conducted using Computational Fluid Dynamics (CFD). This analysis is used to obtain the optimal placement of marine turbine current using 2 variations of distance, that is:

Case 1: Pontoon of turbine system is propped on pile 56 as shown in Figure 13.

Case 2: Distance between the pile foundation 56th to the closest side of the pontoon of marine system with the pile foundation 56th is 3.3 meters, with the purpose that one of the turbine blades is in the position of the maximum current velocity that is 4.5 meters from the pile foundation 56th as shown in Figure 14.

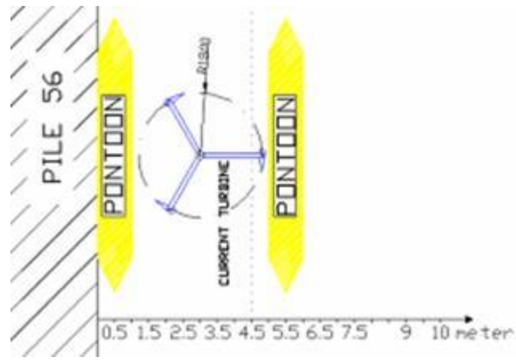

Figure 13: Case 1 of turbine system placement

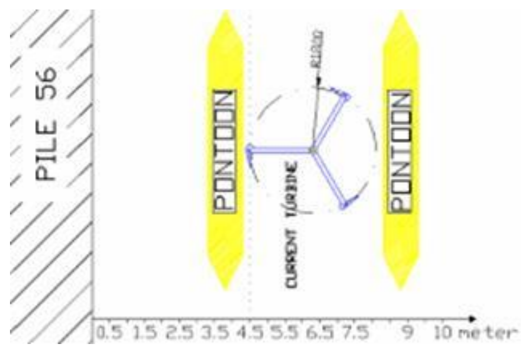

Figure 14: Case 2 of turbine system placement

Numerical modeling by CFD that conducted using 2D modeling is shown in Figure 15 and Figure 16. This modeling is based on Figure 13 and Figure 14. The boundary conditions given are as follows:

Inlet	=	Green Arrow in Figure 15 and Figure 16. Y-direction. The value come from variations in ocean current velocity per meter from pile 56 to pile 57 [m / s].
Outlet	=	Static pressure with a parameter value 0 Pa
Wall	=	The left side, the parameter is smooth wall.
Outlet	=	Static pressure with a parameter value 0 Pa
Symmetry	=	The right side, which is shown in the direction of the red arrow opposite each other.
Object	=	3 blades and 2 pontoon, the parameter is smooth wall.

The fluid that used is sea water with a density of 1025kg /m^3 with an average temperature of 25^{o}C. The type of analysis taht used in this CFD is steady state.

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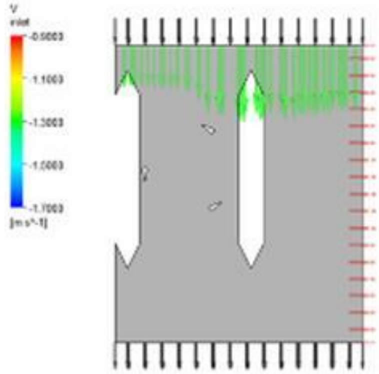

Figure 15: Boundary condition of case 1 in CFD

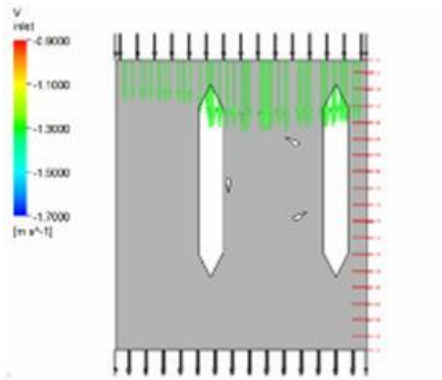

Figure 16: Boundary condition of case 1 in CFD

After CFD simullation has been conducted, then some samples (10 samples) were taken from the inflow average velocity (at red line) and outflow average velocity (at blue line) as shown in Figure 17. kthen the loss value in the CFD simulation is calculated using the equation (2). The results of the loss value between CFD and the results of measurements at the research location are compared, and obtained an error margin of 4.95%, the margin error value is below the 5%, so that it can be said that the CFD numerical modeling results can be said to be valid.

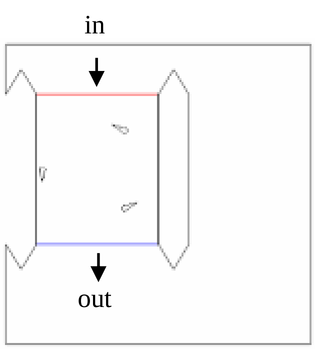

Figure 17: Velocity measurement of current in and current out over survey data and numerical CFD

Table 1: The result of comparison over survey data and CFD

Type	Velocity [m/s]		
	Current in	Current out	Loss
measurement data at survey location (average)	1	0.6	0.0081549
CFD (average)	1.48046	1.09	0.0077706
		margin error	4.95%

The CFD simulation results in Figure 19 and Figure 20 show that the flow pattern around blade 2 has similarities with the flow pattern of the tests that has been conducted by Fujisawa and Shibuya (2011) in Figure 18.

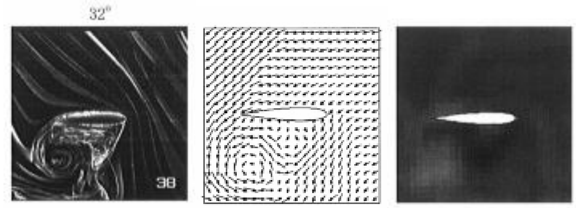

Figure 18: Velocity vector contour around the blade in angle 32 degree from experiment Fujisawa and Shibuya (2011)

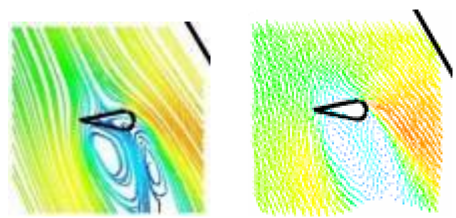

Figure 19: Velocity vector contour around the blade 2nd in angle 30 degree from CFD

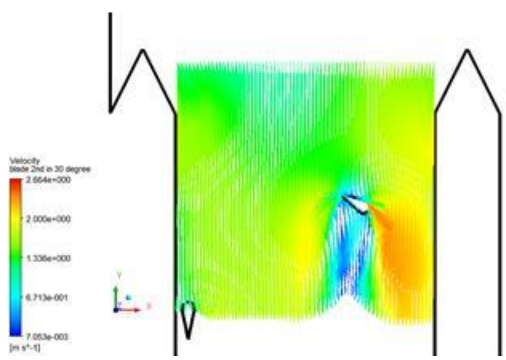

Figure 20: Velocity vector contour around 2 marine turbin pontoon and blade 2nd from CFD

In Figure 21 shows comparison of pressure contour of marine current turbine in case 1 and case 2 using CFD. In Figure 22 shows comparison of velocity contour of marine turbine in case 1

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and case 2. While Figure 23 shows comparison of velocity vector of marine current turbine in case 1 and case 2 using CFD. And in Figure 24 shows comparison of velocity streamline of marine turbine in case 1 and case 2.

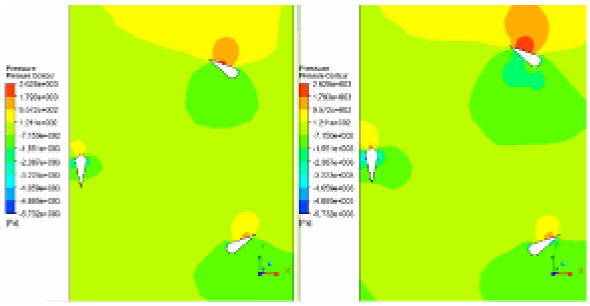


Figure 21: Pressure contour of case 1 and case 2 in CFD

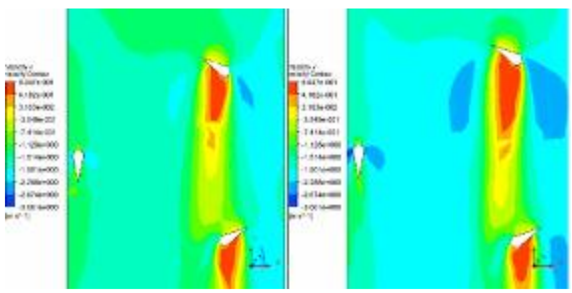


Figure 22: Velocity contour of case 1 and case 2 in CFD

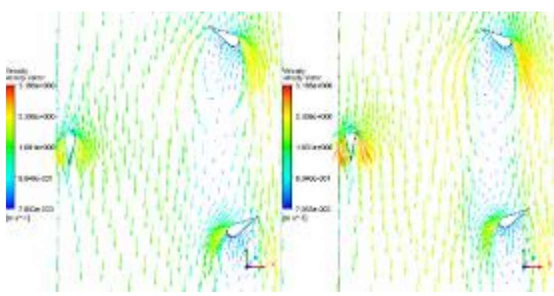


Figure 23: Velocity vector of case 1 and case 2 in CFD

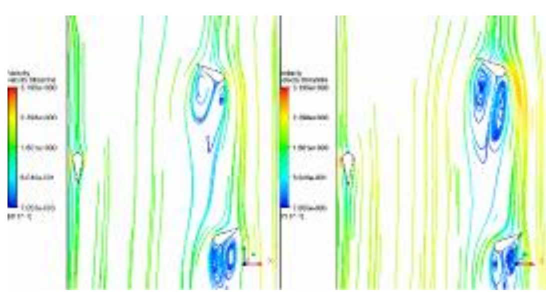
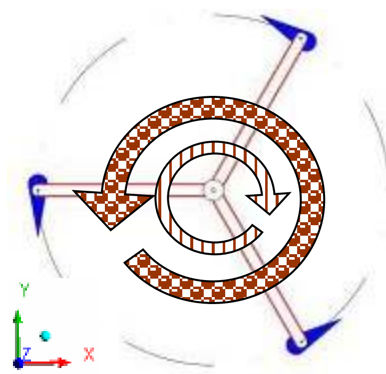


Figure 24: Velocity streamline of case 1 and case 2 in CFD

From Figure 21 to Figure 24 show the visualization of the fluid around the blade of marine current turbine. In case 2 shows the distribution and pressure values that occur around the blade are much larger than the case 1. Whereas the total pressure, force, and average velocity values for the three blades in Case 1 and Case 2 are shown in Table 2 to Table 6. While the torque value shown in Tabel 7, where the rule of torque rotation is shown in Figure 25. The results in case 2 show that the torque value is much greater than the torque value in case 1, where the relationship between power and torque is directly proportional, if the torque value is large, then the power value is large too. Thus, the best placement for marine current turbine is in the case 2 location, which is 3.3 meters from foundation pile 56 to the side of the nearest pontoon from foundation pile 56, or 6.3 meters from pile 56 to the turbine axis.



: Counter clockwise (CCW) rotation, using simbol (-)

: Clockwise (CCW) rotation, using simbol (+)

Figure 25: The rules for torque rotation of marine current turbine

Table 2: The CFD result of pressure in case 1 and case 2

Blade	Pressure Case 1		Pressure Case 2	
	Total	Units	Total	Units
1	-293876	Pa	-517060	Pa
2	-145581	Pa	-173311	Pa
3	-209320	Pa	-264399	Pa

Table 3: The CFD result of force in case 1

Blade	Force			
	x	y	Total	Units
1	13.8671	-239.701	240.1018	N
2	-237.232	-1226.63	1249.36	N
3	160.42	-836.57	851.8122	N

Table 4: The CFD result of force in case 2

Blade	Force			
	x	Y	Total	Units
1	9.33465	-367.831	367.949426	N

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2	-334.682	-1540.39	1576.32909	N
3	197.866	-949.784	970.175551	N

Table 5: The CFD result of velocity in case 1

Blade	Velocity			
	x	Y	Total	Units
1	0.055315	-1.33695	1.51835	m/s
2	0.254984	-0.31288	0.91206	m/s
3	-0.4053	-0.32232	0.963464	m/s

Table 6: The CFD result of velocity in case 2

Blade	Velocity			
	x	Y	total	Units
1	0.122077	-1.66315	1.86784	m/s
2	0.348815	-0.36625	1.08983	m/s
3	-0.424676	-0.4175	1.04268	m/s

Table 7: The CFD result of torque in case 1 and case 2

Blade	Torque Case 1			Torque Case 2		
	Z-axis	Units	Direction	Z-axis	Units	Direction
1	-432.183	N.m	CCW	-662.309	N.m	CCW
2	2248.848	N.m	CW	2837.392	N.m	CW
3	1533.262	N.m	CW	1746.316	N.m	CW
Total	3349.926	N.m	CW	3921.399	N.m	CW

4.0 CONCLUSION

From the results of this study obtained several conclusions, namely:

1. The measurement results at the location show a minimum ocean current value of 0.8 m/s located at the position of 1 m from foundation pile 56, while the maximum current value of 1.9 m/s is at the position of 4.5 m from foundation pile 56
2. Measurement results at the site show a minimum sea depth of 10.8 m and a maximum depth of 12 m.
3. The numerical simulation results of CFD show the total value of turbine blade torque for case 1 is 3349.926 N.m and case 2 is 3921.339 N.m. The total value of torque in case 2 is greater than case 1. Because the relationship between power and torque is directly proportional, the value of the electrical power in case 2 is much larger than case 1.
4. The best placement recommendation for marine current turbine is in case 2, which is 3.3 meters from foundation pile 56 to the side of the nearest pontoon in foundation pile 56, or 6.3 meters fromfoundation pile 56 to the turbine axis.
5. With an average depth of 11 meters in the case 2 location, it is necessary to conduct further research on the appropriate method for anchoring rope anchors in marine current turbines.

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