Study on ocean turbulence intensity around the Goto Islands by field observation and numerical simulation

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https://doi.org/10.15017/1785433

出版情報：九州大学, 2016, 博士（工学）, 課程博士
バージョン：

（様式３）Form 3

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論 文 名　: Study on ocean turbulence intensity around the Goto Islands by field observation and numerical simulation（五島列島近辺の海洋乱流強度に関する海洋観測と数値シミュレーション）

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論 文 内 容 の 要 旨

Over the last decades different environmental, social, economic and political actors have attempted to promote research and usage of alternative energy resources. In the special case of Japan, the dependence on imported fuels and the nuclear accident in Fukushima in 2011 have led to focus on the promotion and development of renewable energy resources. As an island country, ocean energy exploitation represents a great opportunity for Japan. In this regard, the Goto Archipelago in Nagasaki Prefecture was set as test site for ocean energy converter developers to test prototype devices under real conditions. One of the key factors that tidal current energy has to face up nowadays is determining the influence of turbulence conditions in the behavior of converter devices. First, high turbulence intensity values lead to narrower wakes in the streamwise direction and high loading fluctuations, which has a negative impact on the fatigue of the structure. On the other hand, unexpected extreme velocity values might lead to turbines collapse or crash.

The present study is focused on evaluating the turbulence conditions for a future tidal energy farm in three different channels in Goto Islands. This prediction is based on field observation and numerical model simulation. The first procedure is based on the data collected by two different devices. In two of the three locations an Acoustic Doppler Velocimeter (AVM) was set with a 32 Hz sampling rate, collecting point current speed information at 3 meters over the sea bottom. In a third location, a newly developed Acoustic Doppler Current Profiler (AD2CP) was used to measure velocity data at an 8 Hz sample rate. Since the geomorphology of a channel is expected to have an important effect in these large scale vortex generation, depth measurements campaigns were also carried out to get high accuracy bathymetries of the areas of interest. A preliminary analysis which consists of a signal noise elimination and a data rotation to define the velocity on a new coordinate system based on streamwise, transverse and vertical components is done. Peak values even a 100% higher than the mean velocity were found. After this first stage, turbulence is quantified by different parameters, being the most important of them the turbulence intensity since it relates the strength and fatigue of turbine blade. The results obtained fluctuate between 0.1 and 0.3 when the current velocity is over the cut in speed for most of the tidal turbines and it was observed that turbulence is strongly influenced by the morphologic conditions. Turbulence is parameterized also in terms of integral time scale and integral length scale, being notably large the values obtained, which gives an idea of the large scale turbulence nature of the flow. Comparing the turbulence parameters obtained by the AVM and AD2CP at the correspondent layer, the results obtained by both devices were found comparable, setting aside the differences due to the installation position and its surrounding area.

At the same time, a FVCOM numerical model simulating the hydrodynamic nature in the sea area around

Goto Archipelago was developed and, subsequently, validated with velocity and tidal level measured data above mentioned. Although the FVCOM code includes a turbulence closure scheme module developed by Mellor and Yamada, the values calculated for turbulent kinetic energy and, consequently, for turbulence intensity do not adapt to the real conditions due to the large scale nature of the turbulence. For this reason, a new approach which takes more into account the geomorphologic factor is proposed. This method combines the above mentioned Mellor and Yamada module with a new formula, which consists of a second degree polynomial based on a dimensionless parameter dependent on mean velocity, vorticity and a depth related parameter calculated by subtracting the distance to the bottom from the total depth. This new proposed method is validated on the basis of the turbulence intensity values obtained with the data measured by the AD2CP at different depth layers. A good correlation between the measured data and the values provided by the new approach was found both for ebb and flood tide direction for velocity magnitudes higher than 0.5 m/s, with some discrepancies under this limit. Nevertheless, this disagreement is acceptable since it only occurs for velocities under the cut-in value of most of the converter devices which are being developed. Finally, this new numerical tool is used to create turbulence intensity estimation maps of the three areas of interest at different depths and during different tide moments.

This dissertation is divided in four different parts. The first one is an introduction to the main issue of the study. In this regard, an energy policy review and a state of art of renewable energy, especially focused in tidal current energy, is presented in Chapter 1. Chapter 2 introduces the theory related to turbulence and the numerical model used to simulate the flow conditions around the area of study. Afther this introductory information, Chapter 3 is focused on the field observation campaigns, describing the area of study, the measuring devices used and also giving a brief description of the measured tidal current velocity characteristics. In Chapter 4, turbulence conditions at the points studied are quantified on the basis of different parameters, with particular attention to the turbulence intensity. The numerical model validation and results are presented in Chapter 5. The new approach used to calculate turbulence intensity for a large scale turbulence nature flow is also presented and evaluated by comparing it to the measured data in this chapter. Finally, this approach is used to create turbulence intensity prediction maps of the areas of interest, which are presented in Chapter 6 together with other conclusions.