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A Study on Omnidirectional Ocean Wave Spectral Shape with Bimodal Index

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The wave spectrum defines the characteristics of a sea state, which can be used to determine the environmental load required to design marine structures. The wave spectral shape is related to the distribution of energy over wave frequency. This paper presents an analysis of the shape of the ocean wave spectrum based on eight years of wave records off the west coast of Korea's Jeju Island, which is located between the Yellow Sea and the East China Sea. The ocean wave spectral shape is classified according to the bimodal index (β), which is a shape parameter based on spectral moments. The average shape of the classified ocean wave spectrum was compared with the bimodal Joint North Sea Wave Project (JONSWAP) spectrum, and the relationship between its five shape parameters and the bimodal index has been investigated in this study. It was confirmed by comparing with observation data that the ocean wave spectral shape can be represented by the bimodal index alone, including the energy concentration and distribution of both peaks.

INTRODUCTION

To develop and utilize marine resources, including ocean energy, the characteristics of natural forces of the target ocean area need to be identified. An ocean wave, one of the representative external forces in the ocean, is generally defined as a wave spectrum because the various frequency-dependent energy components are superimposed. A wave spectrum is used in numerical simulations and model tests to predict the load on coastal/offshore structures, the performance of wave energy converters (WECs), and so on. The ocean wave spectrum can be derived by directly measuring and analyzing wave records, but this is challenging because of time, cost, and risks such as loss of data and instruments. For this reason, when the waves are not measured, the wave spectrum of the target site is assumed to be the same as that of the adjacent ocean area or well-known wave spectrum models.

There have been many previous studies on defining the wave spectrum in the form of a mathematical formula that satisfies the physical processes of waves based on ocean observational data and theories. Phillips (1958) proposed a saturation range spectrum, which provides an upper bound for the spectrum of gravity waves in deep water. Pierson and Moskowitz (1964) proposed a spectrum for fully developed wind seas, which assumes that the wind blows steadily for a long time over a large area. Bretschneider (1959) introduced a wave spectrum form that uses the wave height and period, and Mitsuyasu (1970) modified this approach by using both the wave spectrum and theoretical relation between the wave height and period. For the Joint North Sea Wave Project (JONSWAP) spectrum, the peak developed by a strong wind within a limited fetch is sharper than the wave spectrum of the fully developed wind sea. Hasselmann et al. (1973) analyzed the fetch dependence of the wave spectrum by parameterizing a least-squares fitted analytic function and proposed a JONSWAP spectrum that artificially enhances the spectral density around the peak based on the Pierson–Moskowitz spectrum. These models are widely used in the design of the coastal and offshore structures, especially in extreme conditions (Mackay, 2016).

The energy conversion performance of the WECs is significantly dependent on wave frequency. When the wave energy is defined by the traditional method using only significant wave height (H_{m0}) and energy period (T_e), even if the wave energy is the same, there may be a difference in the power generation of WECs depending on the energy distribution with the wave frequency. Therefore, the wave spectral shape representing the energy distribution according to the wave frequency is important in evaluating the performance of the WECs in the ocean.

Recently, the demand for ocean development has been increasing on the west coast of Korea's Jeju Island, located between the East China Sea and the Yellow Sea. In particular, the Korea Wave Energy Test and Evaluation Center has been constructed for demonstrating the technology of prototype marine renewable energy devices. As part of defining the characteristics of ocean wave resources at the test site, the shape of the ocean wave spectrum was analyzed using 33,965 wave records observed over eight years by Korea Research Institute of Ships and Ocean Engineering. This paper focuses on finding the bimodal wave spectrum model that can represent an ocean wave spectral shape. A bimodal index (β) based on spectral moments is introduced to parameterize the ocean wave spectral shapes. A five-parameter JONSWAP spectrum is used to represent the unimodal and bimodal spectral shapes. The correlation between the five spectral shape parameters and the bimodal index was derived to present a bimodal wave spectrum model based on the bimodal index.

OCEAN WAVE OBSERVATION

Ocean waves were observed from 2009 to 2016 on the west coast of Jeju Island at the border between the Yellow Sea and the East China Sea. Ocean waves were recorded using an acoustic Doppler current profiler, a wave-measuring instrument installed on the sea bottom. The depth of the observation location is 40 m and 2.5 km away from the coast (33°19′41″ N and 126°8′12″ E), as shown in Fig. 1.

Table 1 presents the observation status of the ocean waves for about eight years. The wave records were sampled at 2 Hz for about 17 min, and each included 2,048 surface elevation data.

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