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Conditional Probability Approach of Assessing the Risk of High Ocean Waves

Yeesock Kim
Associate Professor, Dept. of Civil Engineering and Construction Management, California Baptist University, Riverside, CA, U.S.A.

Nathaniel Small
Undergraduate Student, Dept. of Civil Engineering and Construction Management, California Baptist University, Riverside, CA, U.S.A.

Kyu-Han Kim
Professor, Dept. of Civil Engineering, Catholic Kwandong University, Gangneung, South Korea

Jong-Wha Bai
Associate Professor, Dept. of Civil Engineering and Construction Management, California Baptist University, Riverside, CA, U.S.A.

Nuoyi Zhu
Graduate Student, Dept. of Civil, Environmental and Architectural Engineering, Worcester Polytechnic Institute (WPI), Worcester, MA, U.S.A.

ABSTRACT: The objective of this paper is to develop a framework to assess the potential risk for high ocean waves detected by high frequency radar systems. High ocean waves due to earthquakes, strong wind, and/or other climate conditions have become one of the major natural hazards. Various coastal disasters including beach erosion along the shoreline are also caused by high waves. In order to decrease the damage caused by coastal disasters, it is essential to predict high ocean waves and assess their risk. Using the Bayesian approach, conditional probability of exceeding high ocean wave threshold is estimated with the predicted wave heights, which are calculated based on the measured data from high frequency radar systems. The data used is drawn from two Wellen radar systems that were installed in Samcheok City, Gangwon-do on the East Coast of South Korea. Additionally, Monte Carlo analysis is conducted to estimate conditional probability of exceeding the given threshold against coastal hazards. The preliminary results demonstrate that the proposed framework is effective in estimating vulnerability due to high ocean waves. It is expected that the proposed framework will provide adequate warning for people to evacuate from threatened coastal areas. Hence, this approach will directly contribute to the reduction of injuries and deaths due to natural disasters by supplying near real-time data of the environment around coastal areas.

1. INTRODUCTION

It is generally said that it is very difficult to predict costal and/or ocean characteristics, including wave heights and periods in a variety of engineering and science domains, e.g., physical oceanography, wave forecasting, ship routines, and coastal protection. Hence, a great attention has been paid to the development of effective data collection approaches for the ocean wave information. One of the commonly adopted methods is high-frequency (HF) radar (Zhu et al. 2016).

Several HF radar systems are commercially available for ocean surface condition monitoring. The first research on the HF radar system was conducted by Barrick et al. (1977). They collected ocean wave current spectrums. Paduan and Roesenfeld (1996) measured ocean currents using the CODAR system developed by Barrick et al (1977), and Prandle et al. (1993) proposed a new ocean current measurement system called the Ocean Surface Current Radar (OSCR) system. In 1986, Wellen radar (WERA) system was developed by Gurgel et al. (1986) to estimate ocean surface currents and wave height. Hickey et al. (1995) also developed ocean current prediction system, which is called the high-frequency ground wave radar (HF-GWR). Other innovative HF radar systems as follows; the VHF Courants de Surface MEsurés par Radar (COSMER) developed in the University of Toulon in France (Broche et al., 1987); Coastal ocean surface radar (COSRAD) by James Cook University in Australia (Heron et al., 1985); High-frequency ocean surface radar (HFOSR) at the Okinawa Radio Observatory Communications Research Laboratory (ORO/CRL) in Japan (Takeoka et al 1995); Multi-frequency coastal radar (MCR) in the University of Michigan, Ann Arbor (Teague et al., 2001); Ocean States Measuring and Analyzing Radar (OSMAR2000), developed by Wuhan University in China (Huang et al., 2002); and the PortMap system (Heron et al., 2005).

Although, the applications for the HF radar systems to ocean condition monitoring are widely used, the reliability of such systems has yet to be fully addressed. With this in mind, central to this paper is the development of a reliable framework for the estimation of the risk with wave spectrum using the HF radar data.

2. METHOD OF ANALYSIS

2.1. Case Study Region

In order to demonstrate the effectiveness of the proposed framework, extensive field data was collected. Samcheock City, Gangwon-do, located in the east coast of South Korea was selected as the case study region, because of its propensity for high ocean waves. The installation sites of the radar systems were locations with optimal radio-wave transmitting environments for data reliability, good geological conditions as well as high accessibility. Out of four candidates, two sites at Imwon Harbor and Hujung Beach were selected as ocean radar installation sites (see Figure 1).

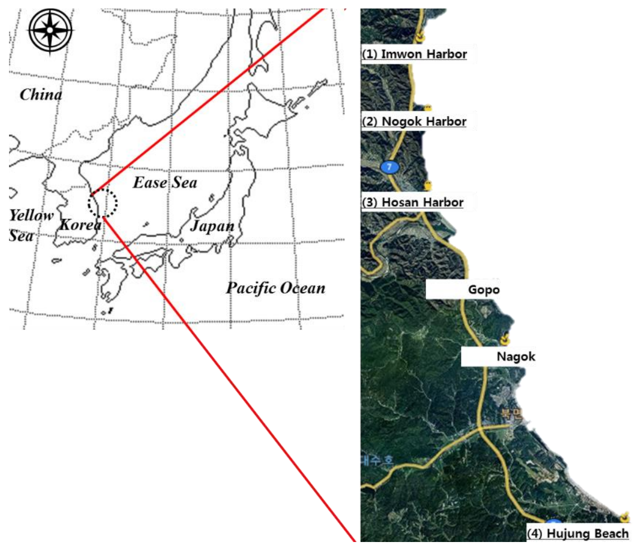

Figure 1: Study area for ocean radar installation.

2.2. Experimental Data

The ocean radars in the subject area operated at a frequency band of 24.525 MHz with a bandwidth of 150 KHz for 1 km (0.621 miles) lattice spacing resolution. The azimuths of the center beam at Imwon Harbor (Site A) and Hujeong Beach (Site B) are 95.8° and 37.3° respectively with the range of ± 60° from the central angle (see Figure 2). Each site had a 60-minute cycle for recording wave height and current velocity data. In this study, the current wave velocity date was collection from July 1, 2014 to July 11, 2014.

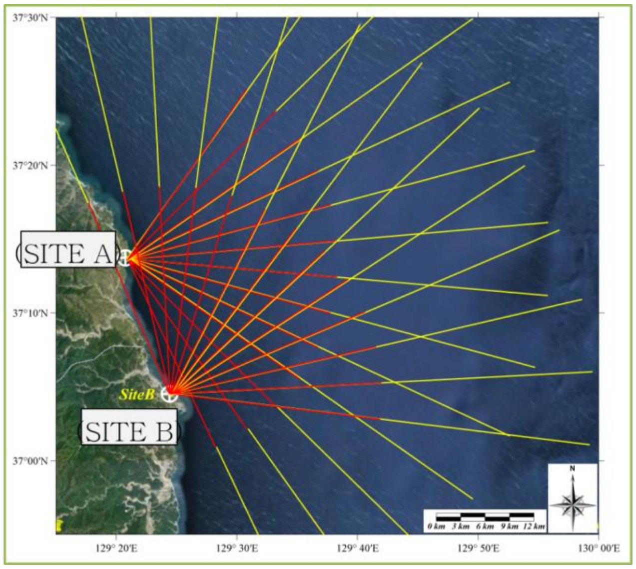

Figure 2: Monitoring pints and range.

Figures 3 and 4 show the sample data sets of current wave velocity and the corresponding wave heights. The data points used in this study are the maximum wave velocity and the maximum heights measured every 60-minutes over a 10-day period. It should be noted that two cycles of data are missing, providing a total of 238 points for this study.

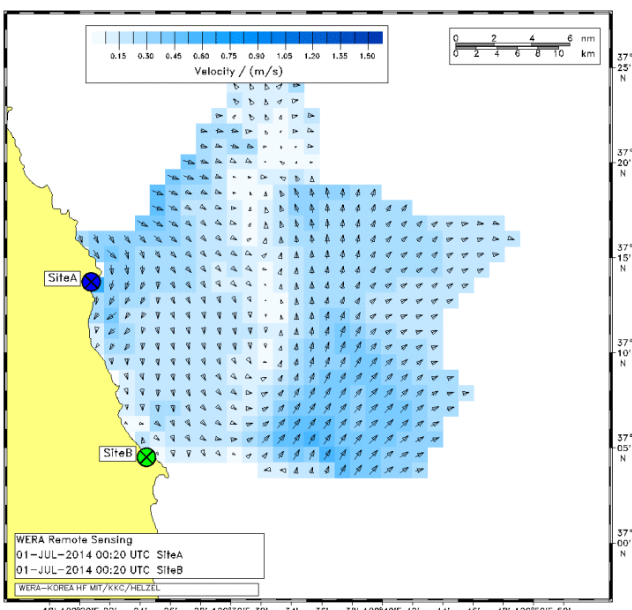

Figure 3: Current wave velocity data of case study region (July 1, 2014 00:20).

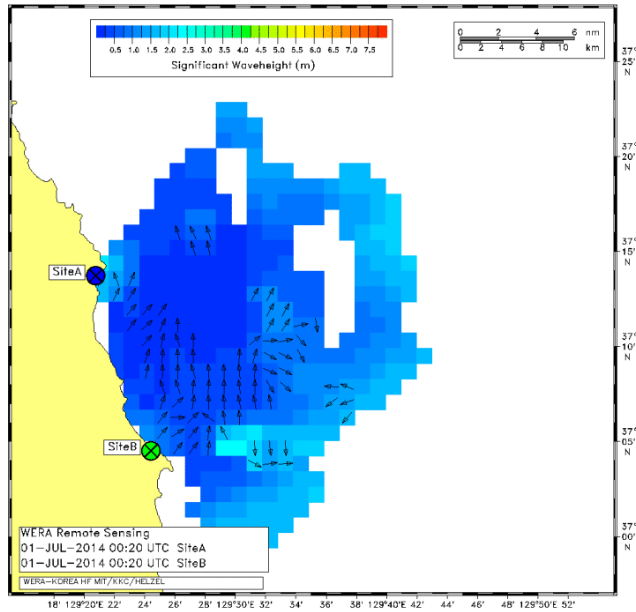

Figure 4: Wave height data of case study region (July 1, 2014 00:20).

2.3. Probabilistic Demand Model

Using the collected data from the ocean radars and the wave heights, a probabilistic demand model is developed to describe the relationship between current wave velocity and the corresponding maximum wave height. Eq. (1) shows the model from a probabilistic linear model.

$$D(CV;\mathbf{\Theta}) = \theta_0 + \theta_1 \ln(CV) + \sigma\varepsilon \qquad (1)$$

where $D(CV;\mathbf{\Theta}) = \ln[h(CV;\mathbf{\Theta})] =$ natural logarithm of the demand, h; $\mathbf{\Theta} = (\theta_0, \theta_1, \sigma)$ is a vector of unknown parameters; ε is a random variable representing the error in the model with zero mean and unit standard deviation; and σ is the standard deviation of the model error. The logarithmic transformation is used to approximately satisfy the normality assumption (i.e., ε has the Normal distribution) and the homoscedasticity assumption (i.e., σ is constant).

Table 1 summarizes modeling parameters of the probabilistic demand model, and Figure 5 shows the probabilistic demand model.

Table 1: Model parameters of probabilistic demand model.

Parameters	Mean	St. dev.	Correlation coefficient		
			θ_0	θ_1	σ
θ_0	1.11	0.0163	1.0		
θ_1	0.34	0.0266	−0.248	1.0	
σ	0.244	0.0112	0.0002	−0.0015	1.0

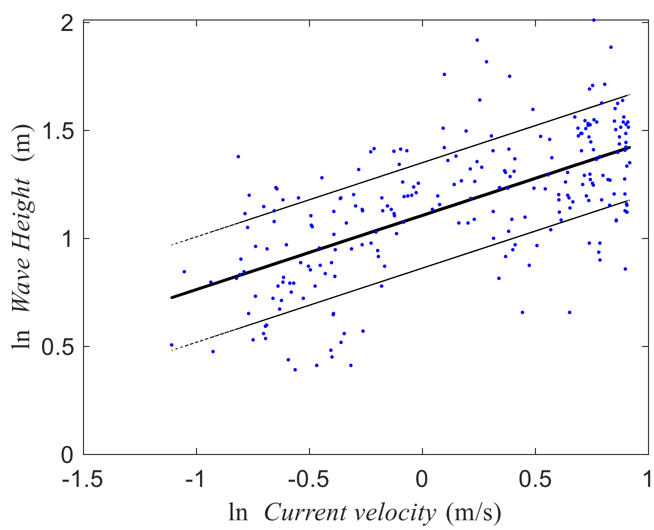

Figure 5: Probabilistic demand model.

For threshold limits, three levels of ocean wave heights are used, based on the literature (Kim and Shim 2012). The limits include low, moderate, and high waves, and the corresponding heights are 2.0, 3.0, and 5.0 m (6.56, 9.84, and 16.4 ft.), respectively.

Figure 6 shows the relationship between the given wave heights and the predicted values using the demand model.

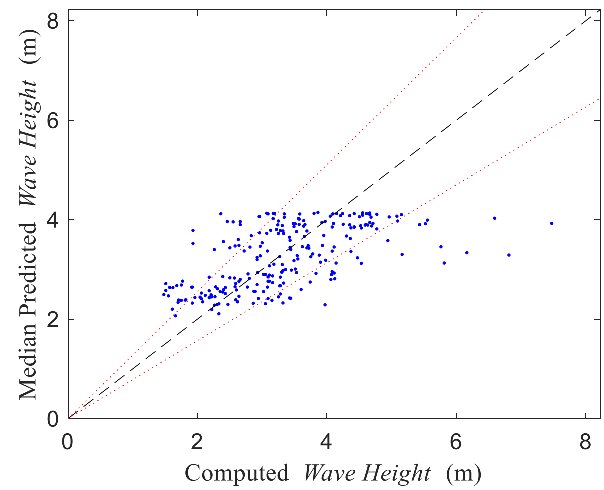

Figure 6: Predicted wave heights using the probabilistic demand model.

2.4. Conditional Probability Approach

Risk of high ocean waves is defined as the conditional probability of attaining or exceeding a specific threshold limit for a given current wave velocity. To estimate the desired risk, several parameters including current velocity, wave height responses, and uncertainties are necessary to be defined. A set of curves is developed using Monte-Carlo simulations. Figure 7 shows the conditional probabilities for the case study.

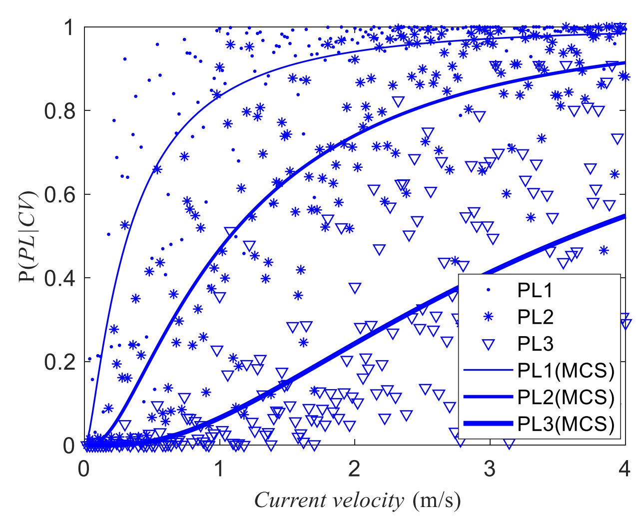

Figure 7: Conditional probability estimates for high ocean waves.

As shown in Figure 7, probability estimates with 1 ~ 2 m/s (3.28 ~ 6.56 ft/s) against low- to moderate-level waves are higher than 50%. It is noted that the average value of the measured current velocity out of 238 data points is 1.35 m/s (4.43 ft/s), and the corresponding probabilities due to three levels of wave heights are 89.0, 59.3, and 12.3%, respectively. Based on these preliminary results, the conditional probabilities of attaining or exceeding wave height thresholds are substantial, especially for low- to moderate-level waves.

3. CONCLUSIONS

This paper focuses on the development of a framework assessing the potential risk for high ocean waves detected by high frequency (HF) radar systems. Conditional probabilities of attaining or exceeding high ocean wave thresholds are estimated using the Bayesian approach. For developing a probabilistic demand model, a total of 238 data points are used from the HF radar system. The preliminary results show that the risk probability estimates are substantial, particularly for low- to moderate-level ocean waves.

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