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Estimation of the significant wave height in the nearshore using prediction equations based on the Response Surface Method

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ABSTRACT

Response Surface Method (RSM) is introduced to develop prediction equations in order to estimate nearshore wave height from offshore wave data when the nearshore measurement data were not available or sufficient. The main idea of introducing RSM and developing such prediction equations is to gain a practical and fast estimation of nearshore wave height for a specific region as a substitute for the time-consuming and sophisticated numerical wave model in the case of long-term wave estimation or frequent wave forecasts. A numerical wave model and a semi-analytic fit model derived from the wave energy flux conservation equation were used to fit the response surface of nearshore wave height and develop the prediction equations. The Haitan Strait located in the nearshore area of China East Sea was selected as the studying area. A series of measured wave data obtained from an offshore buoy and 2 nearshore ultrasonic wave gauges from 30th October 2015 to 28th March 2016 were taken as an example. The predictions given by the proposed equations have correlation coefficients of more than 0.85 and root mean square errors of less than 0.19m which are very reasonable when the equations are considered to be concise, efficient and practical.

1. Introduction

Wave height is one of the most important environmental parameters for ocean and coastal engineering. The assessment of wave height in project site is a primary task for the design, planning and construction of coastal and ocean structures. Unfortunately, in most nearshore regions, wave data are not always available or sufficient to determine the wave heights due to the paucity of measurement or limited length of records. One of the most common and reasonable way to determine the wave height is to estimate from nearby offshore buoy by considering the wave propagation process (Browne et al., 2007; JTS-145-2015; Strauss et al., 2007). However, in nearshore area, seabed topography can be very rugged and complex including hilltops, slopes, valleys, etc. Previous studies show that, the wave heights in nearshore area vary spatially due to the complicated bathymetry (Berkhoff, 1973; De León et al., 2005) and are greatly affected by the wave transformation processes, for example, shoaling, refraction, diffraction and islands sheltering (Rusu et al., 2008; Zheng et al., 2009), thus making the estimation of nearshore wave height a complicated problem.

The most challenging part in estimating nearshore wave height from offshore waves is the accurate calculation of offshore-nearshore relationship by considering the wave transformation processes. Theoretical attempts were reported in previous literature based on a 2-dimensional theory and mild-slope assumptions (Arthur et al., 1952; JTS-145-2015; Koh and Le Méhauté, 1966), but in complicated seabed areas, these theoretical methods may cause notable errors. Innovative methods such as Artificial Neural Networks (ANNs) and Fuzzy Logic (FL) have become a practical and popular tool in recent decades in solving complex correlation problems in ocean engineering. Previous literatures show that ANNs and FL can give reasonable predictions in wave propagation and wave forecast problems in nearshore regions (Browne et al., 2006; Jain and Deo, 2006; Londhe and Deo, 2004; Makarynskyy, 2004; Özger, 2010; Özger and Şen, 2007). However, the model training procedures usually require a large amount of nearshore measurement data which are not always available. Besides, these innovation methods based on machine learning languages are not very user-friendly and practical for engineers to apply.

Over the recent decades, significant advances have been made in the simulation of wave propagation. The third-generation spectral wave prediction models, such as WAM and WAVEWATCH, have been widely

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used for large-scale wave forecasts and hindcasts all around the world (Group, 1988). Based on the spectral wave model, efforts had been devoted to adding shallow water physics to meet the needs for simulation in nearshore areas, such as SWAN and MIKE21 Spectral Wave Module (Booij et al., 1999; DHI, 2012). Based on these models, successful simulations of nearshore wave propagation and predictions in various regions around the world have been conducted (Aboobacker et al., 2013; Aydoğan et al., 2013; Manson, 2012; Strauss et al., 2007). Numerical wave models were proved to be an effective and powerful tool to solve wave propagation problems. However, in the simulation of nearshore waves, very fine mesh is usually required in order to capture the complicated seabed topography, which always leads to a great number of computational time and memory allocation. The computational time can be extremely long and unacceptable for long-term data estimation. In another case, wave forecasts in the construction site are always not available and engineers have to estimate from offshore wave forecast frequently during the construction (Chen et al., 2015). It may cost too much time and labor for an engineer to use the time-consuming and sophisticated numerical model to make frequent (like hourly) nearshore wave forecast. Under these circumstances, the numerical wave model may not be an efficient and practical tool to apply (Güner et al., 2013).

In statistics, the Response Surface Methodology (RSM) is used to explore the relationship between several explanatory variables and one or more response variables (Box and Wilson, 1992). In general, such a relationship is always unknown but can be approximated by a proper fit model and virtualized as a surface, namely response surface (Khuri and Mukhopadhyay, 2010). With the response surface, one can easily obtain the response value on the surface through the fitting function of the surface instead of exploring the explicit relationship. The general strategy of RSM is: (1) gain a series of sample points of the response variable y against input variables x_1 , x_2 , x_3, …, x_k . (2) find a proper fit model $y = f(x_1 , x_2 , x_3, …, x_k)$ of the response surface to describe the relationship between input and response variables. (3) process a best-fit procedure to test the fitting goodness and obtain the fitting equation of response surface. (4) use the equation to predict the response for various applications. In the light of the RSM strategy, if the complicated offshore-nearshore wave height relationship is regarded as a nonlinear input-response system, with the response surface of this system, the output nearshore wave height can be conveniently gained on response surface and the mathematical expression of the response surface can be regarded as a prediction equation of nearshore wave height. To apply the RSM, the response surface usually needs a series of sample points to fit, but the nearshore wave data are not always available to provide sufficient sample points. By taking advantage of the advanced numerical wave model, these sample points can be easily obtained in a well-calibrated numerical wave model by running a series of specific wave cases. Then the response surface can be developed by processing a best-fit procedure to the sample points with a proper fit model and the fitting function can be regarded as a prediction equation of nearshore wave height.

In the present work, the offshore-nearshore wave relationship is regarded as an input-response system in which the input parameters are offshore significant wave height H_0, corresponding wave period T_0 and water level L and response parameter is nearshore significant wave height H. Then the Response Surface Method (RSM) was introduced to develop concise and practical prediction equations as a substitute for the sophisticated and time-consuming numerical wave model. The process and methodology to develop and validate such equations are illustrated in Fig. 1. Firstly, a numerical wave model in the studying site was developed and well calibrated using 10-day wave data. Then a series of sample points of nearshore wave height H against input offshore wave height H_0 and period T_0 were generated in the numerical wave model for the fitting of response surface. Secondly, based on wave energy flux conservation, an equation with undetermined coefficients was derived as a fit model for the response surface. The response surface and its mathematical expression were then gained through the best-fit procedure to the sample points and the fitting equation was regarded as a prediction equation of nearshore wave heights. To further improve the model, the effect of water level changing on wave height was linearized and introduced in the fit model as well. Finally, the results using the proposed prediction equations were compared with measurements from 30th October 2015 to 28th March 2016.

2. Example site and data sets

2.1. Description of the site

The example site lies in the Haitan Strait between Fuzhou City and Pingtan City in the nearshore area of China East Sea, as demonstrated in Fig. 2. It is an island area. The seabed in this region is rugged and complex with slopes and valleys. The example site has limited fetch in most of the directions but is directly open to the China East Sea in the northeast. The destructive waves generated by strong monsoon from the northeast in offshore propagate into Haitan Strait and bring high waves in nearshore area. Influenced by the complex terrain, wave height in this area becomes difficult to determine.

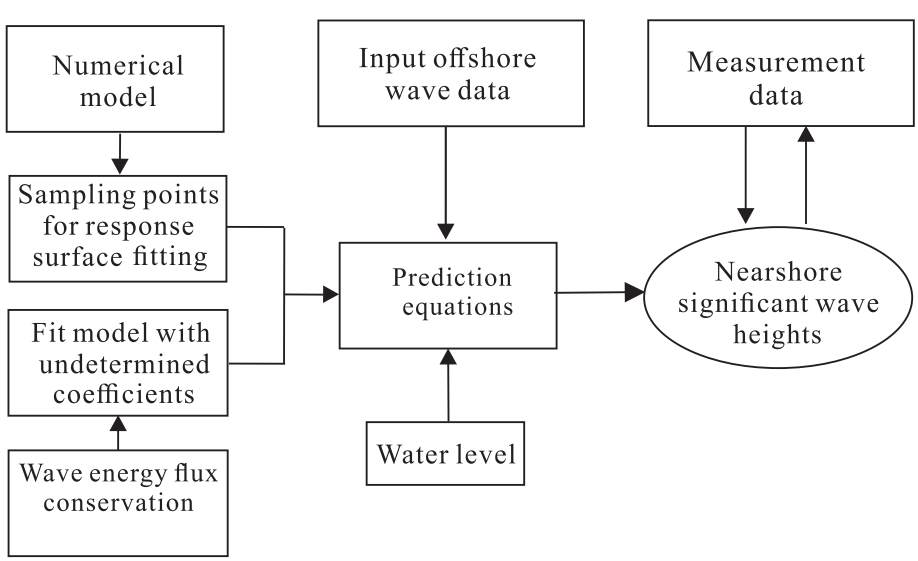

Fig. 1. Schematic description of this study.