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Prediction of Infra-gravity Swash Motions on Natural Beaches using Model Trees

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ABSTRACT: Occurrence of extreme storm waves predisposes natural beaches to erosion. During occurrence of these storm waves, infra-gravity swash energy plays an important role in the amount of erosion created. The available formula for infra-gravity swash is only based on wave heights and wave length and its accuracy is low. Recently, model trees have been introduced as one of the new methods in the data mining approaches that give all possible relations between the involved parameters. In this paper, a new model based on hydrodynamic parameters including the surf similarity, momentum flux and non-dimensional characteristic velocity parameters is presented by using the M5′ and MARS model trees. To generate and evaluate models, all of 579 field data available in literature was used. The results indicated that the developed MARS model improves the RMSE and R values by 42% and 26%, respectively, and the M5′ model improves these values by 16% and 12%, respectively, in respect to the most common empirical model. According to sensitivity analysis of MARS model and also results of M5′ model, the non-dimensional characteristic velocity parameter showed the most correlation and the surf similarity parameter showed the least correlation with infra-gravity swash motions. The performance of developed models is also compared with a numerical study implemented on Tizimin beaches in Mexico.

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1- Introduction

Natural beaches play a critical role as the main defense media against the risk of flooding and erosion in coastal areas. Wave run up is a significant parameter that specifies whether overtopping will happen or not. It is defined as the vertical distance between still water level (SWL) and the highest point reached by the wave tongue and composed of two components namely wave setup (the mean water level height at the shoreline) and instantaneous swash.

Swash component is defined as the instantaneous fluctuations around mean water level. The swash motion is often separated into two categories based on the wave frequency (f): (i) Infra-gravity ranges, S_{ig} ($f < 0.05$); and (ii) incident ranges, S_{inc} ($f \geq 0.05$) [1]. It is shown that the empirical parameterization of wave run up based on its components has less scatter than similar parameterizations of wave run up. Generally, the incident and infra-gravity swash has been parameterized based on the combination of deep water wave height, wave period and beach foreshore slope [1, 2]. Based on the field studies, a number of parameters involved in wave run up; while, a substantial scattering of data attributed to variation in the infra-gravity swash process. In the present study, the M5′ and MARS algorithms as the alternative approaches are employed to predict infra-gravity swash. A comprehensive database including 579 field data available in the literature was used to develop new models. Three different hydrodynamic parameters including surf similarity, momentum flux and non-dimensional characteristic velocity is applied as predictive variables. Finally, the performance of developed models is compared with Stockdon et al. [1] model as one of the most common existing formulas.

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2- Model Trees

There are two major categories for model trees: (i) Multiple Adaptive Regression Spline (MARS) and (ii) M5 model tree methods.

2- 1- M5′ model

M5′ model tree was originally proposed by Quinlan [3]. It has been improved later in 1997 in a system called M5′ by Wang and Witten [4]. The algorithm constitutes of three main steps: building, pruning and smoothing phases. The basic tree is formed using the splitting criterion. It uses the standard deviation of the class values for each node as a measure of the error at that node, and calculates the expected reduction in error as a result of testing each attribute at that node. An overfitting problem can occur during the model tree construction based on training data. In order to reduce the problem, “pruning” procedure is used. In final step, smoothing process is used to reduce the problem of sharp discontinuousness at the leaves of the pruned tree.

2- 2- MARS model

MARS model is a widely-used non-linear and non-parametric data mining approach that models the non-linear responses of a system to inputs using a series of piecewise linear or cubic segments (splines). MARS algorithm is introduced by

Friedman [5]. In contrast to well-known parametric linear regression analysis, MARS provides greater flexibility to explore non-linear relations between a response variable and predictor variables. In addition, MARS also searches for possible interactions between variables by checking all degrees of interactions. Because it allows for all functional forms and interactions, MARS is able to effectively track the complex data structures and hidden relationships in a high-dimensional dataset.

3- Model Development

The data used to calibrate and validate the M5′ and MARS models were obtained from the field studies of Stockdon et al. [1] and Sénéchal et al. [6]. The employed datasets consisted of totally 576 data points.

In this study, the effect of three non-dimensional parameters on wave runup was studied extensively. These parameters are presented as the surf similarity parameter, the momentum flux and the characteristic velocity. For considering the effect of wave orbital velocities on wave run up, a new parameter, which was obtained by simplifying the vertical velocity of wave particles at breaking point, has been proposed. The non-dimensional characteristic velocity is approximated based on following simplified equation:

$$\hat{u}_s = \frac{u}{\sqrt{gH_b}} = \frac{\sqrt{gH_b}T_p}{4\pi h_b} \quad (1)$$

4- Results and Discussion

One of the main advantages of MARS model is its ability to check whether a specific input parameter makes meaningful contribution to an output variable or it only marginally improves the accuracy of the model. Figure 1 shows the relative importance of input variable obtained based on MARS analysis. As seen the characteristic velocity is the most important parameters in prediction of the infra-gravity swash.

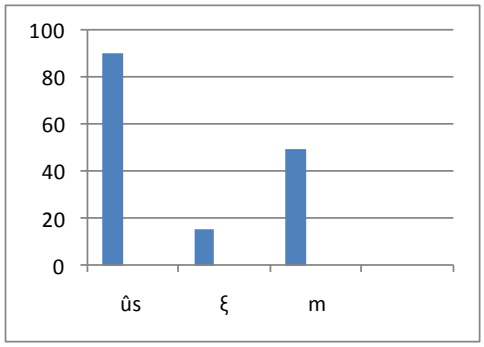

Figure 1. The relative importance (%) of input variables in developing MARS model

To develop a practical equation, the M5′ algorithm is used. The proposed equation based on this algorithm is as follows:

$$\frac{S_{ig}}{H} = 0.2609 m^{0.4302} \hat{u}_s^{0.6563} \quad (2)$$

The surf similarity parameter is neglected by the M5′ algorithm in prediction of infra-gravity swash due to existence of bed slope parameter in this parameter. Stockdon et al. [1] and Guza and Thornton [7] also stated that the infra-gravity motions are independent of bed slope. Therefore, the M5′ algorithm correctly captures this behavior.

The performances of developed models are compared with Stockdon et al. [1] model. The results of statistical error parameters of proposed models are presented in Table 1. According to this table, the developed MARS model improves the RMSE and R values by 42% and 26%, respectively, and the M5′ model improves these values by 16% and 12%, respectively, in respect to Stockdon et al. [1] model.

Table 1. Statistical error parameters of different methods

Model	Bias	RMSE	SI (%)	R
MARS	-4×10^{-14}	0.12	17.5	0.908
M5′	-0.0193	0.18	25.2	0.801
Stockdon et al. [1]	9.6×10^{-4}	0.22	30.3	0.715

For further verification of developed models, the results of infra-gravity swash motions over the Tizmin beach profile with four different foreshore slopes between 0.06 and 0.12 is selected as case study. Figure 2 depicts scattering between the observed and predicted values of infra-gravity swash by different methods. As seen the developed models are more accurate than the Stockdon et al. [1] model.

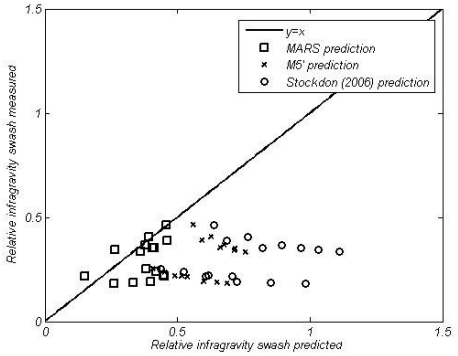

Figure 2. Comparison between predicted and measured relative infra-gravity swash using different methods

5- Conclusion

In the present study, two alternative approaches have been used to develop new predictive equation for prediction of infra-gravity swash motions based on surf similarity, momentum and characteristic velocity parameters. A comprehensive database including 579 field data was collected from previous studies. The result indicated that the proposed models are more accurate than Stockdon et al. [1] model as the most common existing formula.

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