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STUDY OF WAVE-INDUCED SCOUR DEPTH AROUND GROUP OF PILES USING SUPPORT VECTOR MACHINES

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Series of large-scale scouring experiments were done for various arrangements of pile groups with different number of piles and arrangement characteristics to assess the applicability of Support Vector Machines in wave-induced pile group scour predictions. Piles were exposed to waves of shallow water and equilibrium scour depths around them were measured in large-scale wave basin of Ujigawa Open Laboratory of Kyoto University. Finally, the measured experimental data were given to SVM as inputs and the applicability of this data mining model was assessed in predictions of pile group scour properties. Results indicate that, SVM can provide more reliable predictions of scour properties due to waves compared to available empirical formulae.

INTRODUCTION

Various arrangements of pile groups are widely being used as supports of marine structures. As piles are located on erodible beds of the sea, scouring is a threat to such structures and the scour depth amounts should be considered well in their designs. Though most of these supports are constructed in form of groups of piles, majority of studies were concentrated on predictions of scouring around single piles while in case of pile group, the arrangement of the piles and the spaces between them in arrangements as well as their geometry, sediment and wave characteristics should also be studied.

Available pile group scour data due to waves are only based on two main references (Sumer and Fredsoe [1]; Byaram and Larson[2]). Sumer and Fredsoe [1] carried out small-scale pile group arrangements of two piles (tandem and side by side), three piles (tandem and side by side) as well as square group (4*4 piles) in a wave flume of 4 m in width, 1m in depth. Bayram and Larson [2] also investigated the scour around a group of vertical piles in an arrangement of 2*2. They allocated the field data of a pile group located in Ajigaura Beach in Japan. However, neither the experimental nor the field pile group researches include arrangements of 2*3, 2*2 and 3*3 pile configuration.

On the other hand, soft computing methods such as ANN and SVM have been introduced as alternatives for the existing prediction formulas (which are not capable of accurate estimations around pile groups with different arrangements) (Ghazanfari et al. [3]) .

This paper addresses the result of recent large-scale pile group scour studies due to waves carried out in the wave basin of Coastal sedimentary laboratory of Ujigawa Open Laboratory and assesses the applicability of SVM model for wave-induced pile group scour predictions in experimental studies about 3*3, 2*3, 2*2 and 1*2 arrangements of piles.

EXPERIMENTAL SETUP

Series of large-scale experiments were done in 45 m long, 30 m wide and 1m deep wave basin. Various arrangements of 1, 2, 4, 6, 9 piles exposed to waves with the KC numbers of 3.9 and 5.9 in water depth of d= 35 cm and maximum scour depth recorded for each case.

Figure 1 shows the 9 pile arrangement of the experimental model. The gap and diameters of the piles are both 10 cm in all experimental cases.

Figure 1. 9 pile experimental model installed in the wave-basin

The basin is equipped with a piston wave generator and 20 paddles to produce regular waves. The experimental model containing the piles was designed and made of Acrylic. Six wave gauges were adjusted around the model according to Fig1 and one gauge is installed at the separated space to make undisturbed condition for velocity measurements.

Having generated the waves under experimental conditions and recording the wave characteristics, controlling parameters of scouring related to waves were obtained to be used for modeling by SVM.

CONTROLLING PARAMETERS OF SCOURING

Equilibrium scour depth around a single pile due to waves depends on several groups of variables such as the characteristics of wave, the sediment properties and geometry of the pile. In case of a group of vertical piles in addition to the those parameters, spacing between the piles (*G*), number of piles normal to the flow (*n*), and number of piles parallel to the flow (*m*), are also important in estimating scour depth around pile groups. Considering these new parameters, the maximum scour depth (*S*) normalized by pile diameter (*D*) can be best expressed as follows (See also Ghazanfari et al. [3]):

$$\frac{S}{D} = f(N_{RE}, N_s, \theta, KC, \frac{G}{D}, \frac{m}{n}, m \times n) \tag{1}$$

Where N_{RE} the pile Reynolds number, N_s is the sediment number, θ is the Shield's parameter and KC is the Keulegan-Carpenter number defined as follows:

$$N_{RE} = \frac{U_m D}{\nu} \tag{2}$$

$$N_s = \frac{U_m}{\sqrt{g(s-1)d_{50}}} \tag{3}$$

$$\theta = \frac{U_{fm}^2 D}{(s-1)gd_{50}} \tag{4}$$

$$KC = \frac{U_m T}{D} \tag{5}$$

Where S is the equilibrium Scour depth, T is the wave period, d_{50} is the medium sediment diameter, U_m is the maximum undisturbed orbital velocity at the sea bottom just above the wave boundary, U_{fm} is the shear velocity at the undisturbed bed given by $U_{fm} = (0.5f)^{0.5} U_m$ in which f is the wave friction factor, D is the pile diameter, s is the specific gravity and υ is the kinematics viscosity.

Amounts of all controlling parameters were recorded for each experimental case and used for modeling by Support Vector Machines.

MODELING AND RESULTS

Regression algorithms of Support Vector Machines are achieved by some modifications to the classification algorithms of SVM. In support vector regression the objective is to find a function $f(x)$ which has at most ε deviation from the actually obtained targets y_i for all the training data and at the same time is as flat as possible.

The Nonlinear support vector regressions can be used in complex and nonlinear problems by introducing kernel functions. Solving nonlinear problems can be achieved by mapping the data into a higher-dimensional feature space with the help of kernel functions. The problem of support vector regression in the feature space can be written as (6) in the feature space as

$$f(x) = \sum_{i=1}^{m} (\alpha_i - \alpha_i^*) K(x_i, x) + b \tag{6}$$

Where K is the kernel function and α_i and α_i^* are Lagrangian parameters.

In addition to the choice of a kernel, SVM requires the setting up of kernel-specific parameters. Furthermore, optimum values of the regularization parameter C and the size of error in the sensitive zone need to be determined. The choice of these parameters controls the complexity of the prediction. The SVM model requires setting of a few user-defined parameters, such as the regularization parameter (C) and the type of kernel (polynominal or RBF).

In this study, the regularization parameter C and the size of error in sensitive zone parameters control the complexity of prediction. A value of C=40 and ε=0.0010 were selected based on the process of error minimizing and polynominal kernel was selected for mapping the data and the fundamental SVM model was developed based on the data of Sumer and Fredsoe [1] and Byaram and Larson[2] for the training phase.

The recorded data obtained from the experimental studies including the controlling parameters of KC number (*KC*), sediment number (N_s) , Shield's parameter (θ), pile Reynolds number (N_{RE}), as well as configuration parameters of $\frac{G}{D}$, $\frac{m}{n}$, $m \times n$ were used as inputs of SVM and amounts of $\frac{S}{D}$ were predicted as outputs of testing phase used to assess the precision of SVM in scour prediction.

Figure 2 displays the prediction amounts of SVM models for the large-scale experimental data introduced in this paper. In this figure, measured normalized scour depth values of the experiment plotted against the predicted normalized scour depth by the SVM model.

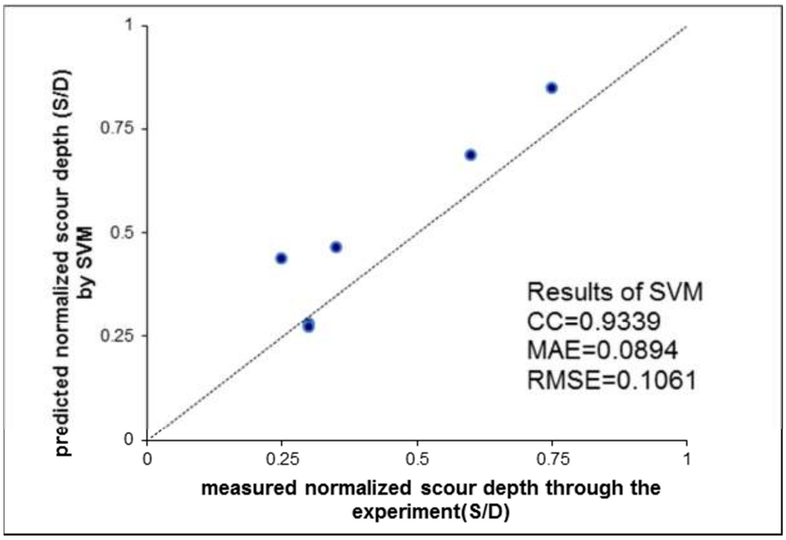

Figure 2. Comparison between the recorded and predicted normalized scour depth by SVM model

Table 1. Performance indices of various approaches to predict scour depth

Approach	Correlation coefficient	Root mean square error	Mean absolute error
SVM	0.9339	0.1061	0.0894
Myrhaug and Rue [4]	0.7323	0.2830	0.2475
Sumer *et al.* [5]	0.2681	0.5729	0.5416

To evaluate the accuracy and applicability of the developed SVM model for the large-scale experimental cases, results were also compared quantitatively with those of existing semi-empirical approaches. Table 1 summarizes the error statistics of all models.

As seen, Support Vector Machines provide better results compared to empirical methods. In addition, comparison between SVM with those of empirical ones shows that current experimental cases with new configurations of pile groups can be modeled accurately using this soft computing model.

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