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A cooperative expert based support vector regression (Co-ESVR) system to determine collar dimensions around bridge pier

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ABSTRACT

In this study, a new procedure to determine the optimum dimensions for a rectangular collar to minimize the temporal trend of scouring around a pier model is proposed. Unlike previous methods of predicting collar dimensions around a bridge pier, the proposed approach concerns the selection of different collar dimension sizes around a bridge scour in terms of the flume's upstream (L_{uc}/D), downstream (L_{dc}/D) and width (L_w/D) of the flume. The projected determination method involves utilizing Expert Multi Agent System (E-MAS) based Support Vector Regression (SVR) agents with respect to cooperative-based expert SVR (Co-ESVR). The SVR agents (i.e. SVR_{Luc}, SVR_{Ldc} and SVR_{Lw}) are set around a rectangular collar to predict the collar dimensions around a bridge pier. In the first layer, the Expert System (ES) is adopted to gather suitable data and send it to the next layer. The multi agent-based SVR adjusts its parameters to find the optimal cost prediction function in the collar dimensions around the bridge pier to reduce the collar around the bridge scour. The weighted sharing strategy was utilized to select the cost optimization function through the root mean square error (RMSE). The efficiency of the proposed optimization method (Co-ESVR) was explored by comparing its outcomes with experimental results. Numerical results indicate that the Co-ESVR achieves better accuracy in reducing the percentage of scour depth (r_e) with a smaller network size, compared to the non-cooperative approaches.

1. Introduction

In many countries, bridges are built across canals and rivers as traffic volume increases due to economic development. Every year several bridges fail, not only for structural reasons, but owing to pier and abutment scouring [1]. Scouring is one of the most significant and destructive effects of floods on bridges. It occurs as a result of the erosive behavior of flowing water on the beds and banks of alluvial channels. Flow approaching a bridge pier or abutment is accompanied by enhanced sediment-carrying capacity. The scour phenomenon may cause catastrophic hazards accounting for reduction of pier support. A number of bridge failures ensuing from scouring have been reported over the past years. A Federal Highway Administration (FHWA) report states that 383 bridges collapsed due to catastrophic floods and scouring [2].

The complex vortex system in the vicinity of bridge piers is the key factor and main reason why scour holes develop. As flow affects the pier nose, a downward flow is formed in front of the pier. This impinges on the stream bed, causing scour-hole formation in front of the pier, and eventually a complex vortex system is formed. In addition, wake vortices are created due to downstream flow separation of the pier, which behave as small tornados instigating the bed material to lift and produce an independent scour hole downstream of the pier. Fig. 1a shows the scouring mechanism around a circular bridge pier and Fig. 1b depicts a bridge which experienced scour during a flood.

Numerous researchers have studied the mechanism of scour phenomenon around bridge and other hydraulic structures like; Link et al., Heidarpour et al., Muzzammil et al., Dey and Raikar, Kirkil et al., Hendrickson et al., and Karami et al. [3–10]. Studying the mechanism of scour, researchers found out that scour phenomenon can be controlled and they proposed various countermeasure methods. The proposed methods are broadly grouped under two distinct categories: armoring and flow-altering countermeasures, which are also described as direct and indirect methods [11]. In the armoring

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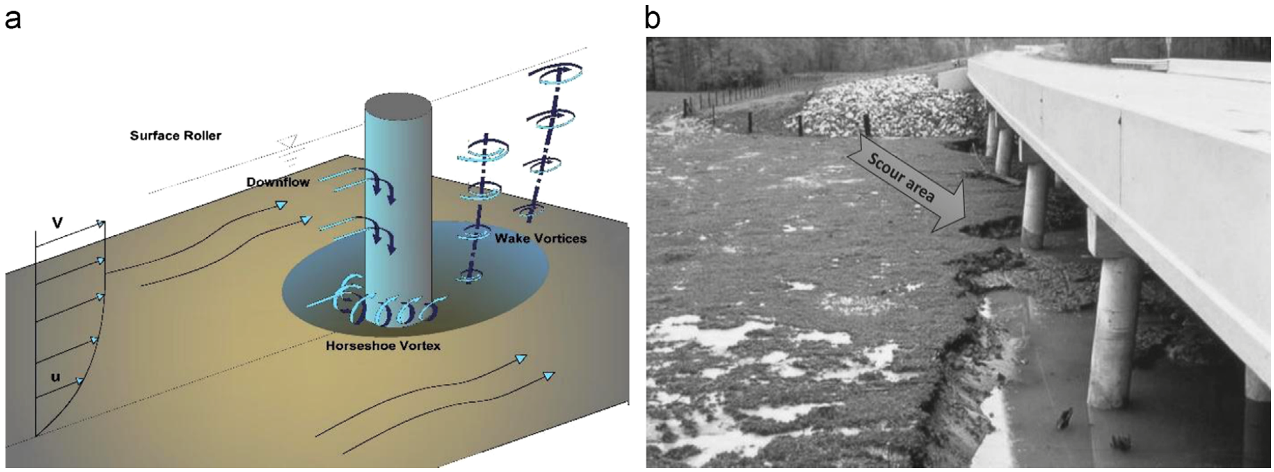

Fig. 1. (a) scouring mechanism around a circular bridge pier (b) bridge scour happened during flood.

technique, the structures are protected directly against scouring by covering the bridge pier area by riprap stones, reno-mattresses, cabled-tied blocks, gabions, tetrapods, dolos, concrete-filled mats or bags, and concrete aprons [12]. In flow-altering countermeasures, the flow pattern is modified by structures such as sacrificial piles and sills, collars, and slots to diminish scour [13].

A collar is a type of indirect countermeasure for controlling scour around piers by diverting the down-flow and acting as an obstacle in down-flow path to reduce the horseshoe vortex strength. Numerous researchers have examined the collar effect on reducing scour depth and its efficiency has been established in earlier studies [14–23]. Despite previous efforts, optimizing collar size in order to reach maximum collar efficiency for protecting pier has not yet been determined. In this paper, the main objective was to find the optimum dimensions of a rectangular collar and several experiments were performed using several sizes of collar in order to find the optimum sizes. But the experiments are too time consuming and expensive then developing a computer-based method is necessary and unavoidable.

As mentioned before, due to expensive procedures of experimental and field work studies, numerical, mathematical and computer-based modeling methods have been considered recently in this scheme.

Soft computing techniques, such as artificial neural networks are employed for predicting scour depth [24–27] and their performance was compared with various existing methods (i.e. fuzzy logic). The results of these studies suggest that the neural network approach performs better than empirical relations [28]. A neural network-based modeling algorithm requires setting up different learning parameters (e.g. learning rate and momentum), the optimal number of nodes in the hidden layer and the number of hidden layers. A large number of training iterations may force a neural network to over-train, which may affect the models' predicting capabilities. The presence of local minima is a further problem when using a back-propagation neural network. Recent studies suggest the usefulness of neuro fuzzy in finding a neural network's optimal architecture for scour prediction. ANFIS was applied to estimate the current-induced scour depth around pile groups [29]. It has been reported [29] that a neuro fuzzy model was utilized to predict the scouring around an arch-shaped bed sill.

Within the last decade, several studies reported the adoption of generalized regression neural networks and support vector machines in civil engineering [30–32], and it was found that they function adequately in comparison to a back-propagation neural network and the neuro fuzzy approach. The advantages of generalized regression neural networks and support vector machines are that both methods require few user-defined parameters and they do not face the problem of local minima.

In view of the enhanced performance by support vector machine based regression in civil engineering, in this study a cooperative-based prediction method is proposed, which applies support vector regression and a multi-agent system. The predicted value of scour depth reduction percentage (r_e) through SVR cooperative agents is implemented to select the optimal collar dimensions around a bridge pier. The expert-based decision maker agent around the bridge scour gathers suitable data to send to the next layer. The multi agent-based SVR in the second layer adjusts its parameters to find the optimal cost function for predicting collar dimensions around the bridge pier to reduce scour around the bridge pier. The weighted sharing strategy selects the optimized cost function through the root mean square error (RMSE). The proposed Co-ESVR compares its performance with two empirical relations, a Polynomial-based (SVR_Poly) and RBF-based SVR (SVR_rbf) in predictions of collar dimensions around bridge piers. In addition, the performance of the proposed Co-ESVR is compared with that of non-cooperative SVR agents.

2. Experimental setup and procedure

The experiments were conducted in the hydraulic laboratory of the hydraulic engineering division at University of Malaya. The experimental flume in the laboratory is 12 m long, 30 cm wide and 45 cm high and has a slope of 0.0004. At the end of the flume there is a basin in which a triangular weir was placed to measure flow discharge with an accuracy of 0.1 l/s. Fig. 2 shows a schematic plan of the experimental flume in laboratory and all the items which are related to scouring process around a bridge pier.

Water was circulated via two pumps. An adjustable tail gate was arranged downstream of the flume to measure the water depth. The water flow velocity was measured by a 3 Axis Electronic Current Velocity Meter and scour depth was measured and recorded by a Sand Surface Meter with an accuracy of ± 0.5 mm in depth. The flume floor was raised 15 cm with metal platforms. A movable bed was prepared by filling an area between the platforms with non-cohesive sediment to lengths of 2 m and 5 m from the beginning of the flume. In the experiment, the bridge pier model was set up in the middle of the 2 m area (the movable bed). The rectangular collars were constructed from rigid plastic with 0.8 mm thickness and were placed on the bed with two sides parallel to the flume walls. The experiments were repeated using various widths as well as upstream and downstream collar lengths to determine the optimum dimensions. Fig. 3 illustrates the plan of three variables in the experiments. Each series of experiments contained 10 distinct experiments. Having 10 experiments for each series, a total of 30 experiments were conducted.