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Predicting optimum parameters of a protective spur dike using soft computing methodologies – A comparative study

Hossein Basser [a,*], Hojat Karami [b], Shahaboddin Shamshirband [c], Afshin Jahangirzadeh [a], Shatirah Akib [a,*], Hadi Saboohi [d]

[a] Department of Civil Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[b] Department of Civil Engineering, Semnan University, Semnan, Iran
[c] Department of Computer Science, Chalous Branch, Islamic Azad University (IAU), 46615-397 Chalous, Mazandaran, Iran
[d] Department of Information System, Faculty of Computer Science and Information Technology, University of Malaya, 50603 Kuala Lumpur, Malaysia

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ABSTRACT

This study proposes a new approach for determining the optimum parameters of a protective spur dike to control scour around existing spur dikes. Several parameters of a protective spur dike were studied to determine their optimum values, including the angle of the protective spur dike relative to the flume wall, its length, and its distance from the main spur dikes, flow intensity, and the diameters of the sediment. To build an effective prediction model, the polynomial and radial basis function are applied as the kernel function of support vector regression (SVR) for prediction of protective spur dike parameters for scour controlling around spur dikes and their performance were compared to Adaptive Neuro Fuzzy System (ANFIS), and Adaptive Neural Network (ANN). Instead of minimizing the observed training error, Polynomial-based SVR (SVR_poly) and radial basis function SVR (SVR_rbf) attempt to minimize the generalization error bound so as to achieve generalized performance. The performance of proposed optimizer was confirmed by experimental results. The results showed that an improvement in predictive accuracy and capability of generalization based SVR can serve as a promising alternative for existing prediction models.

1. Introduction

Using spur dikes, as an indirect technique, for scour and erosion prevention in rivers and canals is one of the common and economic methods. Spur dikes are usually preferred to be built in groups and they may be constructed at a specified angle relative to the bank. These structures lead to a considerable reduction of the flow velocity near banks, creating an area in the water in which there is less motion, which influences deposition, resulting in a reduction in the width thereby creating a defined channel.

Construction of a spur dike in the flow path, causes changes in hydrostatic pressure upstream and downstream of the structure, and this causes a complicated vortex area. These complicated vortex areas, which produce large vortices at the head of the spur dikes, provide the principle local scour mechanism. The mentioned local scour may jeopardize the safety of the structure and eventually lead to structural failure [1]. Fig. 1 shows a schematic diagram of flow and scour pattern around a spur dike.

For the reasons described above, the local scour around spur dikes has been one of the fundamental concerns of researchers for years. The scour hole around spur dikes can be destructive at times, so developing a method to reduce the amount of scour around the spur dikes has become an important and persistent challenges for scientists. Several studies have been conducted to assess the scour depth around spur dikes, e.g., Ahmad [2], Garde et al. [3], Laursen and Christofferson [8], Gill [4], Zaghloul [9], Zhang and Du [10], Gisonni and Hager [5], Karami et al. [13]and Karami et al. [7].

Karami et al. found that in a series of consecutive parallel spur dikes, the first spur dike have the maximum scour depth [7].

Gisonni et al. concluded that spur arrangements without a riprap protection at the front spurs are a poor design, and they should be protected [5].

Generally, the techniques which the researchers used to reduce scour depth around spur dikes, were divided into two main groups, i.e., direct and indirect methods. In the direct method, the structures are protected directly against flow attack by placing

* Corresponding authors. Tel.: +60 129247099 (H. Basser). Tel.: +60 3 79677651 (S. Akib).

E-mail addresses: hosseinbasser@gmail.com (H. Basser), shatirahakib@yahoo.co.uk (S. Akib).

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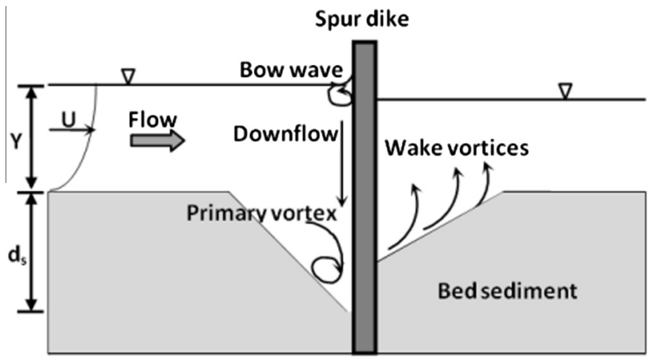

Fig. 1. Schema of flow and scour pattern around a spur dike.

revetments and riprap on spill slopes to resist erosion. In the indirect method, the flow pattern is modified by using a number of special structures, such as a protective spur dike, a guide bank, or a collar, which decrease local scour [11].

Using a protective spur dike as an indirect method has been considered recently. Since spur dikes commonly are built consecutively, the spur dike that is the farthest upstream (henceforth called 'the first spur dike') should be built stronger because it will be subjected to the most destructive influence of flow [12]. Therefore, any attempt to reduce local scour depth around the first spur dike is crucial. The use of a protective spur dike upstream from a set of parallel spur dikes changes the direction of flow and lead to considerable reduction in scour depth around the main spur dikes, especially the first spur dike, which is directly subjected to the flow as it approaches.

Since the protective spur dike is often shorter than the main spur dikes, it is not exposed to significant scour. The main parameters of a protective spur dike that have significant effects on the scour pattern around the main spur dikes are its length, its distance from the protected spur dikes and its angle with respect to the bank [6,13]. In this study, first the effect of the stated parameters on local scour around the protected spur dikes were studied experimentally. 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 have been employed for predicting scour depth [1,14–19] and their performance has been compared to various existing methods, i.e., fuzzy logic. The results of these studies suggest that the neural network approach performs better than empirical relations [20]. 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 [21–23]. The presence of local minima is a further problem when using a back-propagation neural network [24,25]. Akib et al. used Adaptive Network-based Fuzzy Inference System (ANFIS) as a modeling tool to predict the scour depth in bridges. The results from ANFIS were compared with the classical linear regression (LR). ANFIS's results were highly accurate, precise, and satisfactory [26]. Also Keshavarzi et al., used a neuro fuzzy model to predict the scouring around an arch-shaped bed sill, and their results showed well reliability [27].

Within the last decade, several studies have reported the adoption of generalized regression neural networks and support vector machines in civil engineering [28–30], and it was found that the regression classifiers outperforms well in comparison to a back-propagation neural network and the neuro fuzzy approach in terms of prediction. 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 prediction method is proposed, which applies support vector regression. The predicted value of percentage reduction in scour depth (r_e) through SVR is implemented to select the optimal parameters of protective spur dike. The SVR adjusts its parameters to find the optimal cost function for predicting parameters of protective spur dike. The proposed SVR compares its performance with two empirical relations, a Polynomial-based (SVR_poly) and RBF-based SVR (SVR_rbf) in predictions of parameters of protective spur dike. In addition, the performance of the proposed SVR is compared with adaptive neuro fuzzy system and adaptive neural network.

2. Experimental setup and procedure

All experiments were conducted in the Porous Media Laboratory at the, Amirkabir University of Technology in, Tehran, Iran. The flume was a rectangular section that was 14 m long, 1 m wide, and 1 m deep. Glass was used to build the bed and the sides of the flume. Then, a metal frame was used to support the glass flume. Three spur dikes made of Plexiglas were installed in the flume, and they were, 25 cm long (L_f = 25 cm), impermeable, non-submerged, and perpendicular to the flow alignment. The first spur dike was installed 6.16 m from the entrance of the flume. The spaces between the spur dikes were twice their length ($2L_f$ = 50 cm). These values were chosen based on the recommendations of Zhang [32]and Gisonni et al. [31]. A small reservoir was constructed at the downstream end of the flume to collect the transported sediments. The flow discharge was regulated by an inlet valve. A rectangular weir was placed in the flume to measure the discharged water. The approach flow depth (Y) was always set to 15 cm. The flume was filled with uniform bed sediments (σ_g < 1.4), with a thickness of 0.35 m, and specific gravity (S_s) of 2.65, and geometric standard deviation (σ_g) of 1.38. In this study three different sizes of diameters were used to investigate the effect of changing the diameter. The discharge was changed to change the flow velocity (U) in order to achieve different amounts of flow intensity (U/U_{cr}).

Protective spur dikes with different lengths, angles, and distances with the first spur dike also were install upstream of the main spur dikes. Fig. 2 shows a schematic view of the parameters of the protective spur dikes.

Table 1 shows the values of the all variables in the experiments.

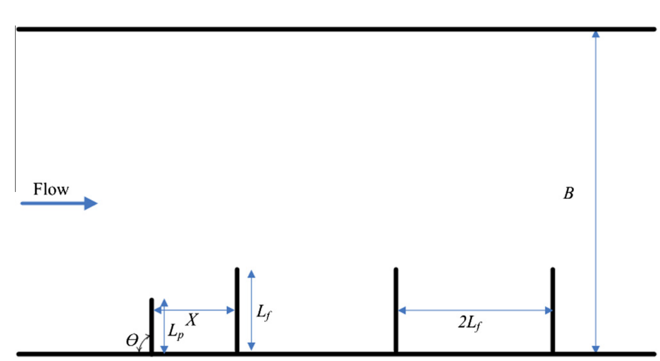

Fig. 2. Schematic diagram of the geometric parameters used in the experiments.