Coastal Engineering 135 (2018) 1–15

Contents lists available at ScienceDirect

Coastal Engineering

journal homepage: www.elsevier.com/locate/coastaleng

An integrated framework of Extreme Learning Machines for predicting scour at pile groups in clear water condition

Isa Ebtehaj [a,b], Hossein Bonakdari [a,b,*], Fatemeh Moradi [a], Bahram Gharabaghi [c], Zohreh Sheikh Khozani [b]

[a] Department of Civil Engineering, Razi University, Kermanshah, Iran
[b] Environematal Research Center, Razi University, Kermanshah, Iran
[c] School of Engineering, University of Guelph, Guelph, Ontario, NIG 2W1, Canada

ARTICLE INFO

Keywords:
Pile group
Scour
Clear water
Model
Application

ABSTRACT

In this study, an integrated framework of Extreme Learning Machines (ELM) was developed to predict local scour depth around pile groups in clear water. The effective variables on local scour at pile groups include flow characteristics upstream of the piles, critical flow conditions related to the incipient motion of particles, pile spacing arrangement, geometric properties and bed particle size. The ELM network was trained and tested using dimensional datasets collected from extensive experiments reported in the literature. The ELM network testing results were compared with a support vector machine (SVM) and artificial neural network (ANN). The most effective variable on local scour depth at pile groups was determined using different sets of input combinations. The proposed ELM model produced a lower error in predicting local scour depth at pile groups than other existing models ($R^2 = 0.99$; $MAPE = 8.75$; $RMSE = 0.007$). The ELM model results were compared with existing artificial intelligence-based and regression-based models. The results indicate that ELM outperformed the existing methods with a high level of accuracy. Moreover, according to an uncertainty analysis of scour depth prediction by the proposed and existing models, the least uncertainty band width for ELM was ± 0.0011 compared to ± 0.0014 for the best existing model. Moreover, an ELM-based equation was proposed for use in practical engineering. Furthermore, a sensitivity analysis was done to study the effect of each variable on the ELM-based equation proposed.

1. Introduction

Several offshore and onshore structures are made with pile foundations on erodible seabeds to provide structural stability (Ghaemi et al., 2013; Bonakdar et al., 2015). Such structures in deep rivers and coastal environments cause flow field changes, which lead to bed scour. These submerged piles may also cause extreme floods – a problem that is responsible for scour hole formation around pile group foundations due to the existence of waves and currents. The spread of scour in hydraulic and coastal structures can also cause structures to collapse (Nielsen et al., 2013; Ataie-Ashtiani and Beheshti, 2006; Bayram and Larson, 2000; Sumer et al., 2001; Zounemat-Kermani et al., 2009; Qi and Gao, 2014; Manes and Brocchini, 2015). Therefore, in response to the complex three-dimensional mechanism in pile groups, safe and economical designs are necessary to accurately assess the scour depth around pile groups. Many studies have addressed the prediction of scour at individual bases (Laursen and Toch, 1956; Breusers et al., 1977; Jain and Fischer, 1979; Ettema, 1980; Yanmaz and Altinbilek, 1991; Melville, 1997; Melville and Chiew, 1999; Mia, 2003; Richardson and Davis, 2001; Zanke et al., 2011; Kothyari et al., 2007; Najafzadeh and Azamathulla, 2013a).

There is little experimental data on the dissimilarity of individual piles in a pile group (Ataie-Ashtiani and Beheshti, 2006; Bayram and Larson, 2000; Hannah, 1978; Coleman, 2005; Salim and Jones, 1996; Sumer and Fredsøe, 1998; Ataie-Ashtiani et al., 2010; Amini et al., 2012). Dietz (1973) studied the effect of the distance between piles and flow skew angle on scour depth at a dyadic pile group. The study results showed that scour depth downstream of the pile is lower than upstream, and it was also noted that scour upstream of piles depends on the distance between piles. Hannah (1978) examined the effect of piles perpendicular to flow and piles in the flow direction. Based on the observations, piles in the flow direction have very little impact on scour depth, while by

* Corresponding author. Department of Civil Engineering, Razi University, Kermanshah, Iran.
E-mail address: bonakdari@yahoo.com (H. Bonakdari).

https://doi.org/10.1016/j.coastaleng.2017.12.012
Received 9 June 2017; Received in revised form 1 November 2017; Accepted 16 December 2017

0378-3839/

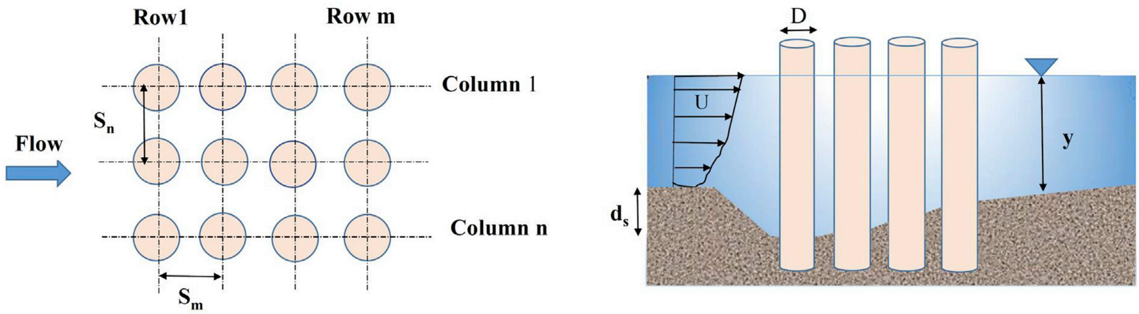

Fig. 1. Characteristics and local scour at pile groups.

Table 1
Statistical indices of all parameters.

Variance	SD	Mean	Max	Min	
0.394	0.62	2.32	4	1	n
1.202	1.096	3.41	5	1	m
0.0003	0.0184	0.035	0.06	0.016	D (m)
0.0047	0.069	0.091	0.33	0.016	S_n (m)
0.0069	0.083	0.096	0.96	0.016	S_m (m)
3.305e-0.8	0.000183	0.00077	0.00098	0.00025	d_{50} (m)
0.007	0.085	0.162	0.24	0.033	y (m)
0.0031	0.056	0.296	0.3608	0.179	U (m/s)
0.006	0.08	0.123	0.237	0.008	d_s (m)

increasing the number of piles perpendicular to flow, scour depth increases. A series of experiments were carried out by Salim and Jones (1996) to study the scour around exposed pile foundations. It was concluded that scour depth decreases with increasing distance between piles. Coleman (2005) proposed a new methodology to forecast local scour depth around complex piers using a combination of existing scour models. The new method was verified with a broad range of local scour depth measurements. The author found that the relative scour depth is depended on complex pier elements. This methodology has the advantage of being conceptually reliable with scour behavior, straightforward and suitable for a broad range of sediment and flow conditions. Ataie-Ashtiani and Beheshti (Ataie-Ashtiani and Beheshti (2006) experimented on pile groups with different configurations. They found that pile groups with a typical distance between piles within the group of less than 1.15 times the diameter (1.15 D) perform like individual piles. The study results indicated that the number of piles perpendicular to the flow direction and the distance between piles are effective parameters on scour depth. Amini et al. (2012) evaluated the effect of submergence ratio on scour depth. It was found that in heterogeneous pile groups, scour depth reduces as the distance between piles perpendicular to the flow direction increases.

Although some tests have been done on pile groups with different arrangements, there is still no unique formula to predict scour depth at pile groups. The US Federal Highway Administration (FHWA) conducted a series of experiments to predict scour depth around individual piles (Richardson and Davis, 2001) and proposed formulas for predicting scour depth at individual bases. The scour depth at a pile foundation can be

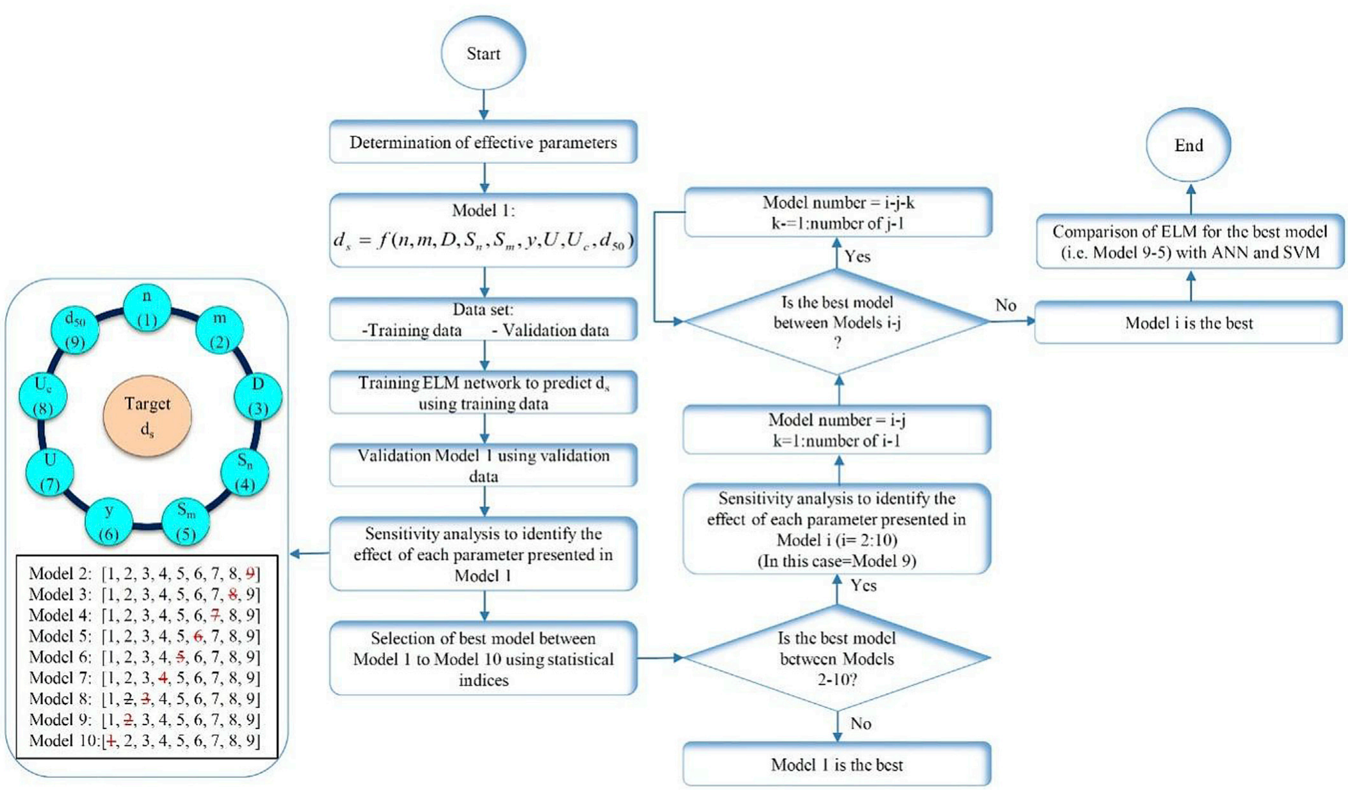

Fig. 2. Study methodology.