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GMDH based back propagation algorithm to predict abutment scour in cohesive soils

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ABSTRACT

In this study, group method of data handling (GMDH) network is used to predict abutments scour depth of bridges which have been embedded in two types of montmorillonite and kaolinite clay soils. The GMDH network has been developed using back propagation technique. Several effective parameters including initial water content, clay content, degree of compaction, and non-dimensional shear strength of bed soils were derived using dimensional analysis for modeling of abutment scour depth. Training and testing results of the GMDH network were compared with those performed using adaptive neuro-fuzzy inference system (ANFIS), radial basis function-neural network (RBF-NN), and traditional equations. Also, efficiency of the GMDH–BP was investigated by different classifications of initial water content (*IWC*) and degree of compaction (*CC*) ranges. Results showed that the GMDH–BP had the higher performance for unsaturated montmorillonite clay with $IWC \leq 25\%$. From the results, it was perceived that this method emerged as the most accurate as ANFIS, RBF-NN, and traditional equations. In particular application, the GMDH network was presented as a new technique for prediction of scour depth around abutment in cohesive bed materials.

1. Introduction

Local scour around bridge abutments is defined as scour due to the change in local flow conditions by the presence of abutments. Abutment local scour in non-cohesive sediments are classified into clear water and live-bed scour (Yokoub, 1995). Since the last few decades, experimental and numerical investigations on abutment scour have been carried out in non-cohesive bed soils (e.g., Liu et al., 1961; Laursen, 1980; Froehlich, 1989; Melville, 1992, 1997; Richardson et al., 1993; Sturm and Janjua, 1994; Abdeldayem, 1996; Biglari and Sturm, 1998; Cardoso and Bettess, 1999; Oliveto and Hager, 2002; Dey and Barbhuiya, 2005b; Dey et al., 2008; Radice et al., 2008). From these researches, several traditional equations have been resulted in limited conditions of field and laboratory. On the contrary, there are few investigations for abutment scour in cohesive soils (Yokoub, 1995; Molinas et al., 1998a,b; Oh et al., 2011). Yokoub (1995) carried out experiments to investigate effects of clay content, degree of compaction, and shear strength of bed soils on abutment scour. His experiments resulted traditional equations for montmorillonite and kaolinite clay soils in saturated and unsaturated conditions of soils. Oh et al. (2011) have used the SIRCOS-EFA (Scour Rate In Cohesive Soils-Erosion Function Apparatus) method for prediction of maximum scour depth in around abutment (Briaud et al., 1999a, 1999b, 2001, 2004; Oh, 2009).

Also, they have suggested the correction factors that are function of abutment shape, alignment, channel geometry, and abutment location. Hosny (1995) suggested that scour process in cohesive materials is fundamentally different from that of non-cohesive materials. It involves not only complex mechanical phenomena such as shear stress and shear strength of soils, but also the chemical and physical properties of the fluid and soil.

It is believed that erosion in cohesive materials occurs when the fluid shear stress is sufficient to overcome the tensile strength of the bed material and submerged unit weight of the soil. In fact, scouring in cohesive soils is more complicated than that of non-cohesive soils. The main factors that could be considered for complexity of the scour in cohesive soils are the physico-chemical soil characteristics and the resistance to scour in cohesive bed material. Also, high concentrations of velocities, bed shear stresses, vortices, down-flows, and turbulence occur at the nose of the abutments propagate scour hole at bridges (Smerdon and Beasley, 1961; Partheniades,1965; Partheniades and Paaswell, 1970; Raudkivi and Hutchison, 1974; Raudkivi and Tan, 1984; Parchure and Mehta, 1985; Debnath and Chaudhuri, 2010). These factors play fundamental role in the scour of cohesive soils. In fact, each of traditional equations has focused on special parameters and it is a limiting factor for prediction of scour depth in cohesive soils.

Recently, various artificial intelligence approaches such as artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS), genetic programming (GP), and gene-expression

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programming (GEP) were applied to develop the modeling of scour depth around hydraulic structures. Also, these approaches overcome to the lack of accuracy, validation, and restrictions of the traditional equations. (e.g., Azamathulla et al., 2005, 2008, 2010, 2011; Guven and Gunal, 2008a, 2008b; Azamathulla and Zakaria, 2011; Najafzadeh and Barani, 2011; Najafzadeh and Azamathulla, 2012; Azamathulla, 2012a, b, in press; Guven, and Azamathulla, 2012; Khan et al., 2012; Guven et al., 2012). Among these methods, the GMDH network is known as a system identification method which is impelled in various fields in order to model and forecast the behaviors of unknown or very complicated systems based on given input–output data pairs (Amanifard et al., 2008). In addition, the GMDH approach is used in different researches such as energy conservation, control engineering, system identification, marketing, economic, and engineering geology (Amanifard et al., 2008; Srinivasan, 2008; Witczak et al., 2006; Mehrara et al., 2009; Kalantary et al., 2009). Recently, alternative GMDH networks have been used for prediction of scour depth around piers and their performances showed that this approach can be provided the best prediction of scour depth than those of traditional equations (Najafzadeh and Barani, 2011; Najafzadeh and Azamathulla, 2012).

The main objective of this study is to investigate the efficiency of the GMDH network for prediction of abutment scour depth in cohesive soils. In fact, application of the GMDH network in scour problems is relatively new and the authors want to compare efficiency of the GMDH-BP with ANFIS, RBF-NN, and traditional equations.

2. Mechanism of abutment scour in cohesive soils

The flow structure that cause abutment local scour is complex in details. This structure can be included down flow, primary vortex, secondary vortex, and wake vortices (Kwan, 1988). The complex flow structure is conceptually illustrated in Fig. 1. At abutment, approaching flow faces a stagnation region which develops a vertical stagnation pressure gradient. Therefore, the stagnation pressure decreases down ward thereafter a net down ward force is created to derive the flow down ward. The jet created by the down flow pushes the bed causing it to erode bed soil and then rolls up and become part of the primary vortex. The primary vortex develops once the initial scour hole is formed and is responsible for the future development of the scour hole (Melville, 1975; Baker, 1980; Yokoub, 1995). The flow accelerates down word into the hole and outward around the abutment in a spiraling motion. In fact, most of the scour holes feature a series of grooves next to the primary scour which suggests that a secondary vortex is included by the primary vortex with an opposite direction of rotation to the primary vortex (Kandasamy, 1985; Kwan, 1988). The vortices are created by the separation of the flow by the upstream abutment corner. The unstable shear layers created by the flow separation roll up to from eddy structures know as wake vortices. The wake vortices are carried downstream by the mean flow and cause an erosion process acting like small tornadoes sucking up material from bed soil. The wake vortices are very weak compared to the primary vortex (Yokoub, 1995).

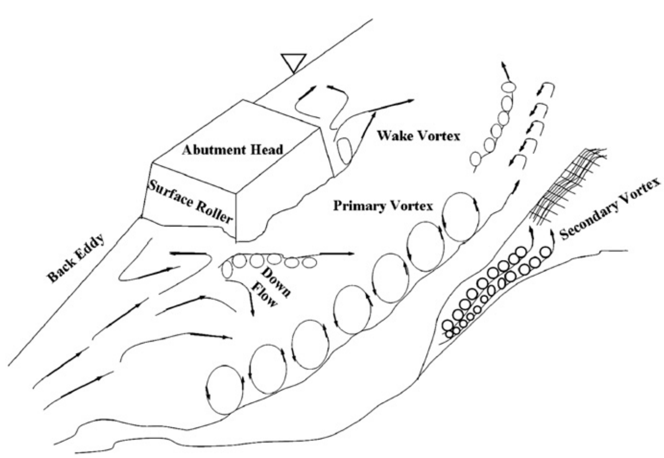

Fig. 1. Flow structure around abutment of bridges.

3. Analysis of effective parameters on abutment scour in cohesive soils

Basis on preceding investigations, scour depth around a vertical abutment in cohesive soils depend on properties of cohesive soils, geometry of abutment, and characteristics of approaching flow (Yokoub, 1995; Molinas et al., 1998a,b). Therefore, the following function can be used to abutment scour depth for clay soils:

$$d_{sc} = f(d_{ss}, y, a, l, U, IWC, C, CC, CT, TS, T, t, g, \alpha, \phi, \rho, \upsilon) \quad (1)$$

where d_{sc} is the scour depth in cohesive soil, d_{ss} is the scour depth in non-cohesive soil for conditions corresponding to d_{sc}, y is the flow depth, a is the abutment with, l is the abutment length, U is the flow velocity, IWC is the initial water content, C is the degree of compaction (%), CC is the clay content (%), CT is the clay type, TS is the torvane shear stress, T is the temperature, t is the duration of experiment, g is the acceleration due to gravity, α is the angle of attack, ϕ is the shape factor, ρ is the water density, and υ is the fluid dynamic viscosity.

The non-dimensional function has been resulted using dimensional analysis as follows:

$$d_{sc} / d_{ss} = f\left(y/a, l/a, IWC, CC, C, CT, Ut / y, \mathrm{Re}, TS / \rho U^2, Fr, \alpha, \phi, T\right) \quad (2)$$

Yokoub (1995) experiments have been carried out with two different models of abutment size. The first abutment has 0.436 m long, 0.218 wide, and 1.2 m height and the second abutment was selected with dimensions half of the first abutment. Yokoub (1995) suggested that non-dimensional parameters of y/a and l/a remained relatively constant values thorough experiments. From preceding investigations, it was found that y/a and l/a have been considered as effective parameters on abutment scour depth in non-cohesive soils (e.g., Cardoso and Bettess, 1999; Dey and Barbhuiya, 2005a; Dey et al., 2008). In this study, y/a and l/a were utilized to predict abutment scour depth in sandy soils.

Furthermore, the values of α and ϕ are kept constant parameters throughout the experiments. The time rate of scour in Eq. (2) is given by the $U \times t/y$. The time duration of experiments varied from 10 to 13 h in order to the scour depth reaches its maximum values and is stabilized. Hence; the time duration has no conspicuous influences on scour depth and it can be eliminated from Eq. (2) (Yokoub, 1995).

From Yokoub (1995) experiments, it was found that physical properties of clay soils such as the median sediment size and geometric standard deviation of the grain size distribution do not exert any influence on the scour depth in cohesive soils. For the free surface open channel flow, the Reynolds number, R_e, is in the fully turbulent zone and its effects will be negligible in the Eq. (2) (Yokoub, 1995; Ettema et al., 1998, 2006; Najafzadeh, 2009; Debnath and Chaudhuri, 2010). The Froude number, Fr, will be used only to predict the scour depth for non-cohesive soil.