Shahid Chamran University of Ahvaz Irrigation Sciences and Engineering (JISE) Vol. 42, No. 1, Spring 2019, p. 83-97

EXTENDED ABSTRACT

Predicting Seepage of Earth Dams using Artificial Intelligence Techniques

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Received:14 March 2014 Revised: 28 June 2017 Accepted: 1 July 2017

Keywords: Firefly Algorithm, Hybrid Models, Seepage Prediction, Earth Dam.
DOI: 10.22055/jise.2017.21384.1537.

Introduction

Preventing water penetration and seepage control is of prime importance in hydraulic structures projects. Recent studies show that 30% of dam failures are due to the seepage from dam's body or foundation. Seepage control inherently is controlling potential energy of water molecules causing seepage and related losses. Constructing a core with low rate of permeability can considerably control seepage from dam body. So foundation seepages are significantly more than body seepages. Foundation seepage control is done to prevent uplift and piping, two phenomena which led to dam failure. One of the methods for controlling seepage from bottom of earth dams which are mounted on alluvial foundation with high rate of permeability, is utilizing a covering layer with low permeability on bed of river, bottom of reservoir (in upstream) and connecting it to central core of dam. In fact, the role of such methods and mentioned covering layer is lengthening flow path for increasing potential losses and decreasing water energy which is terminated to decrease penetrated water and related losses. This covering layer is called clay blanket.

One of the longest upstream impermeable blankets is executed in Tarbela dam in Pakistan with 140 m height. This blanket has 1400 m length and its thickness is 1.52 m at the dam (WCD, 2000). Khalili and Amiri (2015) investigated cutoff effect in reducing leakage, exit gradient and uplift, both experimentally and numerically analyze by software GEOSTUDIO and referring that the results of the software are in acceptable agreement with the experimental results. Tayfu et al. (2005) used Finite Element Method (FEM) and Artificial Neural Network (ANN) models for flow through Jeziorsko Earth fill Dam in Poland. This case study offers insight into the adequacy of ANN as well as its competitiveness against FEM for seepage prediction through an earth fill dam body. Ahmed and Sattar (2014) used Gene expression models (GEP) for prediction of dam failure and results showed the superiority of the developed GEP models over existing regression-based models.

The goal in the proposed study is to introduce the best statistical model to predict the leakage from dams. For this purpose, all important and effective parameters for clay blanket including; permeability coefficient, blanket length and thickness, alluvial foundation thickness and its permeability coefficient, and the ratio of horizontal to vertical alluvial foundation permeability coefficient (which is very effective in seepage from foundation) were modeled with SEEP/W, and seepage values were obtained. Then for choosing the best statistical model, some of the most commonly neural network models comprising FFA, RBF, MLP, GEP and SVR were used. Based on the seepage values, the above-mentioned models were compared.

Methodology

The sample for this study, is a dam which is shown in Figure (1) with the following parameters: K_b: Clay Blanket Permeability Coefficient, L_1: Clay Blanket Length, t: Clay Blanket Thickness, h_f: Alluvial Foundation Thickness, L_2: Clay Core Width in connection point to foundation, K_f: Alluvial Foundation Permeability Coefficient, K_{fy}: Vertical Alluvial Foundation Permeability Coefficient and K_{fx}: Horizontal Alluvial Foundation Permeability Coefficient.

Despite the other studies, in the current study different quantities for the ratio of K_{fx}/K_{fy} based on natural and practical samples to be reliable for real projects and executive works are considered. On the other hand, soil is assumed to be non-isotropic. Some typical values of the effective parameters are given in Table (1). In this study for modeling, SEEP/W software was used and by changing the effective parameters, 350 seepage values were calculated.

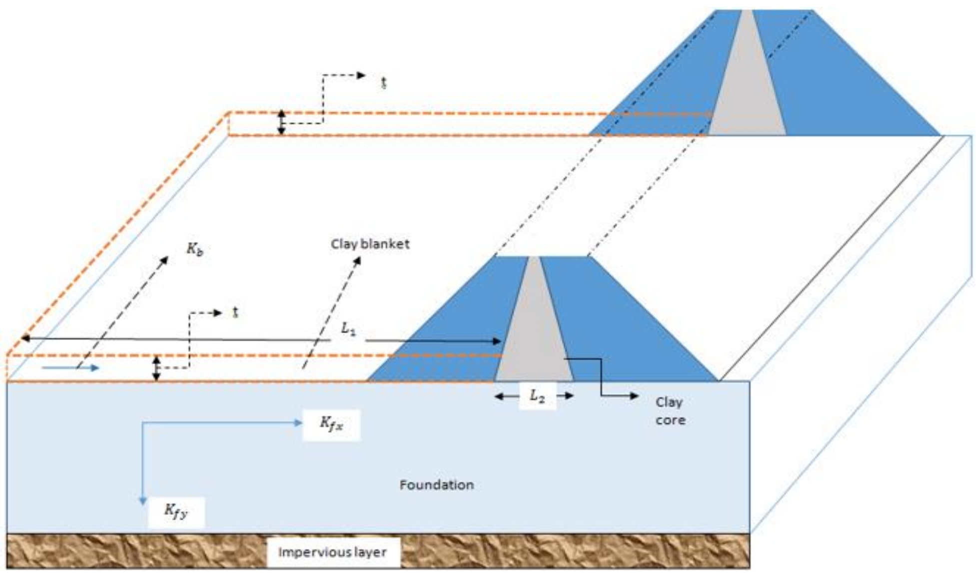

Fig. 1- The geometry of the parameters used in the models

Table 1- Range of the effective parameters in numerical simulations

Clay Blanket	Clay core	Foundation	Parameters
$10^{-6} – 10^{-9}$	-	$10^{-3} – 10^{-5}$	Permeability coefficient (m/s)
0.5 – 1.5	-	25 - 70	Thickness (m)
25 - 400	23 - 83	-	Length (m)
-	-	1 - 15	K_{fx}/K_{fy}

For ease of use, non-dimensional parameter is used. In addition, to achieve acceptable results, the actual values for each parameter were selected (Table 1). Input dimensionless parameters are: (h_f/t), (L_1/H), (L_1/L_2), (K_{fx}/K_{fy}), ($Log(K_f/K_b)$) and the boundary conditions used in the software are zero pressure at downstream and seepage potential at downstream of dam's body. Based on these parameters, numerical modeling was carried out. The simulated seepage values were compared with statistical models including FFA, RBF, MLP, GEP and SVR. Comparison of the intelligent models are based on some standard criteria such as Nash–Sutcliffe coefficient (NS), root mean square error

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(RMSE), mean absolute error (MAE), Willmott's Index of agreement (WI) and Taylor diagram. Some of the results are illustrated graphically and numerically.

Results and Discussion

The seepage values from dam are divided into two data sets: training data set phase (239 records or 75% of the whole data set) and testing data set phase (80 records or 25% of the whole data). The results of statistical models is shown in the Table (2). As Table (2) shows, based on an R^2 = 0.919, Mean absolute error (MAE) = 0.003, Root mean square error (RMSE) = 0.006, Willmott's Index of agreement (Wi) = 0.959 and Nash–Sutcliffe coefficient (NS) = 0.875 in testing data and in training data with R^2 =0.959, Mean absolute error (MAE) = 0.005, Root mean square error (RMSE) = 0.006, Willmott's Index of agreement (Wi) =0.954 and Nash–Sutcliffe coefficient (NS) =0.836, results calculated using Hybrid MLP- FFA model (MLP-FFA) is roughly equal to the amount of numerically simulated seepage.

Table- 2 Results of used models comparison

Models	Parameters	Training phase					Testing phase				
		RMSE	MAE	NS	WI	R^2	RMSE	MAE	NS	WI	R^2
MLP	neuron=5	0.007	0.005	0.796	0.939	0.796	0.009	0.006	0.755	0.913	0.794
RBF	neuron=5, spread=20	0.015	0.012	0.069	0.3	0.069	0.018	0.013	0.083	0.417	0.133
SVR	γ=31.58 , σ=8.95	0.006	0.004	0.821	0.947	0.822	0.013	0.007	0.502	0.804	0.536
GEP	GN=3000	0.014	0.011	0.147	0.45	0.149	0.017	0.012	0.144	0.513	0.175
MLP-FFA	neuron=5	0.006	0.005	0.836	0.954	0.959	0.006	0.003	0.875	0.959	0.919

For each of the models, the scatter plot of data points around line y=x was plotted. For instance, the scatter plot for FFA model is presented in Figure. (2).

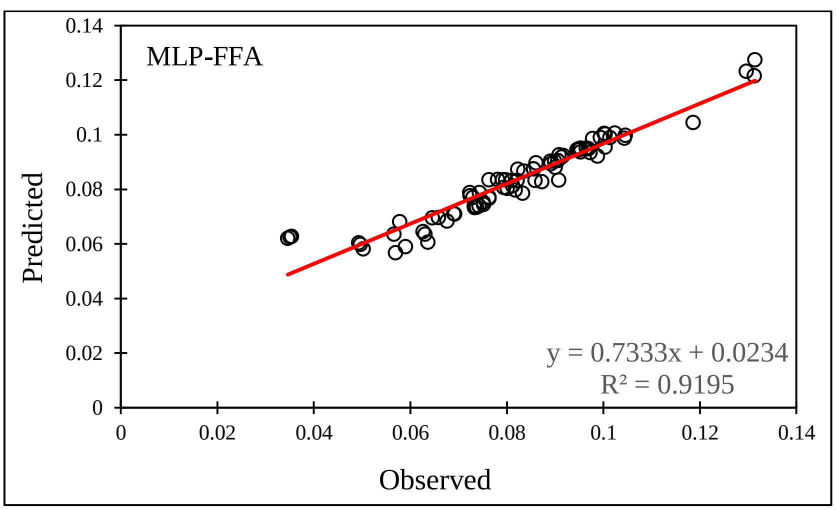

Fig. 2- Performance of the FFA model

Conclusions

The effect of clay blanket at upstream dam reservoir was investigated regarding seepage reduction. According to numerical modelling with FEM and using statistical models, the following results were obtained:

Firefly algorithms in predicting seepage, generates acceptable results. In fact, before designing a clay blanket or leakage values calculation using this algorithm can help to engineers. Also RBF and GEP models, have worst results than the other models. According to the results, clay blanket permeability coefficient and foundation permeability coefficient have high correlation with seepage values and K_{fx} / K_{fy} is the most effective parameter compared with the other parameters, while in other numerical studies the rate of K_{fx} / K_{fy} is assumed equal to 1 that can led to wrong results.

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