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Estimation of Post-construction Settlement in Sloping Core Rockfill Dams utilizing New Predictive Models

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Abstract: *More than 85% of the dam types around the world are earth and rockfill dams. One of the main reasons of damages to these dams is settlement phenomenon which occurs during construction and first impoundment. Therefore, the prediction of dam settlement which depends on many parameters is crucial. The effect of these parameters on each other have made impossible the experimental methods, hence these relationships are of limited accuracy. As a result, these equations have less accuracy in comparison to what exactly occurs. To do so, some models were prepared with the help of GEP method, using data from 19 sloping core rockfill dams throughout the world. Two input parameters namely dam height (H) and dam compressibility index (Ci) were used. Finally, to predict settlement in sloping core rockfill dams (S_{SC}), a form was designed using visual basic (VB). With this form, the settlement can be easily predicted just by entering the desired inputs. In performed predictions in this regard, R and RMSE for GEP method were 0.992 and 0.213, respectively. Regarding the accuracy of the results, this method can be suggested for prediction of settlement in sloping core rockfill dams post-construction.*

Keywords: *Gene Expression Programming; Rockfill Dams; Settlement; Sloping Core.*

I. Introduction

Today, dams - including earthfill or rockfill - are considered as the most important water structures, which play a fundamental role in providing water required for human societies. Thus, stability of dams has particularly attracted attention of the engineers who design these structures, especially in recent decades. Rockfill dams which are constructed by optimal use of local materials are consistent with the site. In this paper, the settlement of rockfill dams with non-permeable sloping core has been studied. In typical situation, the settlement of dam crest can be considered to be 2% of the height of the structure. In seismic areas, a value equals to 1% of the height of the dam would also be added [1]. Earth dam settlement continues for a long time post-construction [2]. In most dams, crest settlement is unequal; however, it might be symmetrical because dam load is maximal at the axial section and it reaches zero at toes. In general, the final value of a dam settlement depends on the foundation and dam load (i.e., its height). Therefore, in order to monitor the performance of a dam, a good evaluation of post-construction settlement is needed [3- 8]. In most of the studies, usually one or several dams were studied in a particular and limited manner [9- 12].

Therefore, an appropriate estimation of the post-construction settlement is required to supervise the performance of the dam and to warn engineers of any possible problem. It is of paramount importance to pay attention to these issues when the predicted values exceed the permissible amount. With respect to what stated above, predicting the settlement of a dam is extremely important. Some limited documents are available [1, 13]. A few relations have been presented in this case and one of the most noticeable relations is the relation offered by Clements (1984) and Lawton and Lester (1964). It can be stated that the common weak point of all the presented relations is their dependency on the single parameter of dam height. The most important factor in dam settlement is its height. However, other parameters such as foundation conditions and materials are effective in dam settlement. In order to overcome these limitation, and to propose a more accurate and simple method, soft computing techniques can be utilized. In the present research, gene expression programming (GEP) is used, which is the method used most to solve complex and varied engineering problems. Finally, a form is implemented and offered using visual basic (VB) software to ease the use of the presented equations.

II. Study of Database

2.1. Data Used

In this paper, according to various previous studies, the two parameters of dam height (H) and dam compressibility index (C_i) [1] were used to predict the settlement of rockfill dams with a sloping core. The data given in the Table 1 is related to 19 rockfill dams with a sloping core. Compressibility index is used to show the overall compressibility of the dam indicating the compaction method, and the quality of foundation materials. This parameter is obtained Eq. 1.

$$C_i = 1 - (i_E \times i_F) \tag{1}$$

Table 1. Range of different parameters used in this study

Parameter name	Parameter type	Unit	Minimum	Maximum	Mean
Dam height (H)	Input (independent)	Meter	23.800	131	72.237
Dam compressibility (C_i)	Input (independent)	-	0.200	1	0.800
Settlement (S_{SC})	Output (dependent)	Meter	0.041	0.579	0.195

where i_E and i_F are indicators representing of the embankment and foundation compaction quality. These indexes vary between [0, 1] [1]. Tables 2 and 3 show the proposed values for these indices. It should be noted that there is not sufficient information about construction method, earth filling, and foundation materials of some dams. In order to develop intelligent models, the 19 data sets were divided into two categories; training and testing. For this purpose, 15/19 data sets and 4/19 data sets were used for training and testing in both methods, respectively.

Table 2. Embankment compaction index [1]

Compaction method	Lift thickness (m)		
	<2	2-3	>3
Compacted with roller	1.0	0.5	0.25
Dumped, sluiced	0.2	0.15	0.1
Dump, not sluiced	0.1	0.05	0.0

Table 3. Foundation quality index [1]

Sound bedrock	Poor or weathered bedrock	Thick riverbed deposit (>10m)
1.0	0.5	0.1

2.2. Evaluation Criteria

Two statistical evaluation criteria were used to assess the performance of the intelligent methods. These criteria are root mean square error (RMSE)and correlation coefficient (R), respectively, given by the Eqs. 2 and 3 [17].

$$RMSE = \sqrt{(\frac{1}{n})\sum_{i=1}^{n}(a_i - p_i)^2} \tag{2}$$

$$R = (\frac{\sum_{i=1}^{n}(p_i - \bar{p})(a_i - \bar{a})}{\sqrt{\sum_{i=1}^{n}(p_i - \bar{p})^2(\sum_{i=1}^{n}(a_i - \bar{a})^2}} \tag{3}$$

where (a) is the actual value and p is the predicted value, ($\bar{a}$) and ($\bar{p}$) are the mean of actual and predicted value, respectively, (e) is the absolute error ($a_i - p_i$), ($\bar{e}$) is the mean of absolute error $\left(\frac{1}{n}\right)\sum_{i=1}^{n}(a_i - p_i)$ and (n) is the number of data sets.

III. Gene Expression Programming (GEP)

3.1. GEP Method

Ferreira suggested a new algorithm according to genetic algorithm and genetic programming. This was called as "Gene Expression Programming or GEP", a new evolved algorithm being used to overcome on most restrictions of GA and GP [17, 18]. Genetic algorithm is a model of machine learning. Its behavior has been inspired from nature evolution mechanism [19]. This method is implementation by creating a population, which its individuals are considered as a chromosome. Then, each individual is designated for evolution process. However, genetic programming (GP) is programmed and analysis for automation. GP is a sub-field of genetic algorithms (GAs) [20]. The main difference between GA and GP is that program evolution in GP is in the form of parse trees, while this program is as binary fibers with constant length in GA [21]. GEP used for rendering solutions is a fiber character with constant length. The solutions have the tree-like structure that is called "Expression Tree or ET". One example of them is represented in Fig. 1.

Fig. 2 depicts GEP algorithm, which selection starts with five elements such as function set, output set, fitness function, control parameters and stop condition. This algorithm randomly builds an initial chromosome, which indicates a mathematical function. Then, it is converted into an expression tree (ET). This method includes two major parts known as chromosomes and expression tree (ET) [17]. GEP has four operators, including selection, mutation, transposition and crossover.

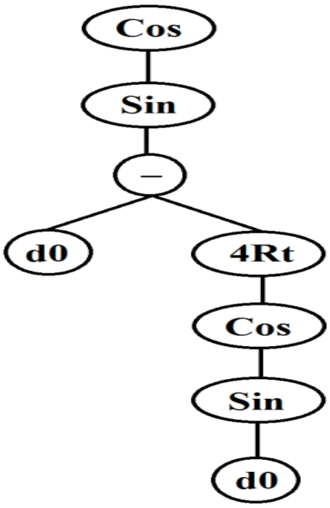

Fig. 1. Exampel of expression tree (ET)

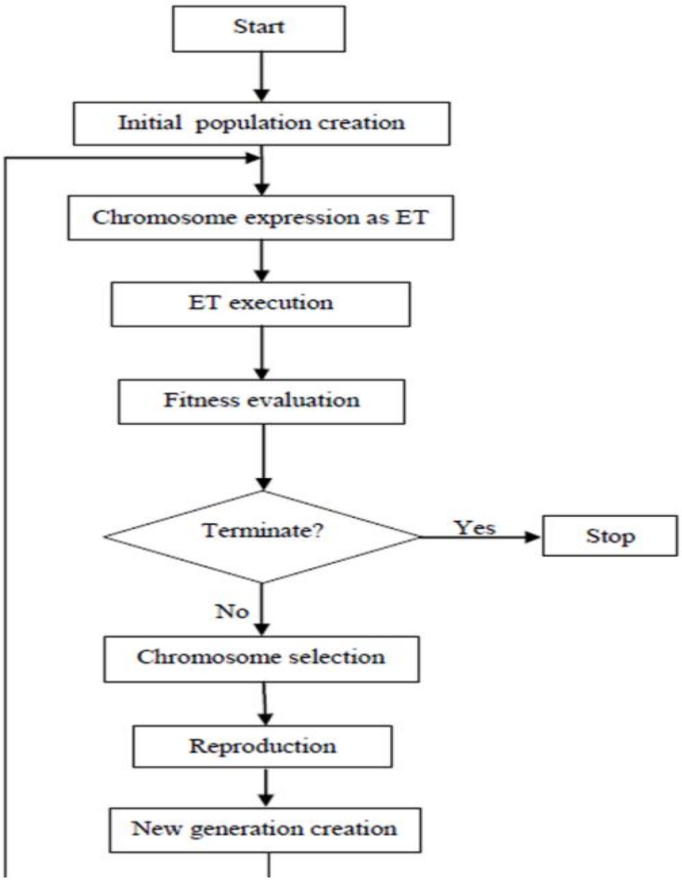

Fig. 2. GEP algorithm [16]

3.2. GEP Model

In this study, GeneXproTools 4.0 software was used to employ GEP method. In order to develop the settlement prediction model, some settings in the software were considered such that chromosome number of 30, head Size of 8, mutation rate of 0.01 and the sum linking function. One of the most important issues is to determine the number of genes which is selected based on the accuracy and application of the built model. To select its optimal number, the trial and error method was used. Given above, this study used three genes for model building and the two constants (real numbers) were used for each gene. Sum (+), multiplication (×), division (/), radical ($\sqrt[n]{X}$), nth power (X^n), natural logarithm (Ln), trigonometric (sin, cos and …), and floor functions ([ ]) were selected for model building. First, with the 80% data sets randomly separated for training, two equations were presented based on two parameters (H, C_i) for predicting the settlement of sloping core rockfill dams (S_{SC}). Eqs. 4 and 5 were presented for predicting the settlement of these types of dams. These equations can be seen in Table 4.

Table 4. GEP equations obtained for Prediction of dam settlement.

Eq.	Eq. No.
$S_{SC} = \operatorname{arcsinh}\left(\frac{C_i}{(\sqrt[3]{[C_i]+88})(\sec(\frac{H+11}{2}))}\right) + \tan(\tan(\tan(\tan(\tan(\frac{H}{7C_i+315}))))) + \operatorname{arcsinh}\left(\frac{\sinh(C_i)}{(\operatorname{arctang}(C_i))([C_i]-\frac{C_i+50}{3})}\right)$	(4)
$S_{SC} = \arctan(\operatorname{arcsinh}(\sin(\frac{26}{(C_i+H)(C_i-19)}))) + \operatorname{arctanh}(\operatorname{arctanh}(\operatorname{arctanh}(\operatorname{arctanh}(\operatorname{arctanh}(\frac{H}{47C_i+329}))))) + \frac{C_i}{Ln(289\sin(C_i)\sqrt[4]{C_i})\sec(\frac{H+47}{2})}$	(5)

Finally, 4 datasets, which were divided for the test, were used for evaluating the achieved equations. Table 5 shows results (Evaluation criteria: R and RMSE) of the study for all equations obtained to predict settlement. The criterion to measure and compare the obtained equations included the RMSE values in the test phase. According to Table 5 and with respect to RMSE, Eq. 4 had the best performance. Fig. 3 shows the values predicted by GEP in both training and test phases for Eq. 4. It is known that Eq. 4 has a good accuracy in both training and testing phases. As seen in this figure, predicted values are very close to actual ones.

Table 5. GEP results to predict sloping core rockfill dam settlement (S_{SC})

Eq. No.	Train		Test	
	RMSE	R	RMSE	R
4	0.046	0.963	0.213	0.992
5	0.058	0.951	0.218	0.999

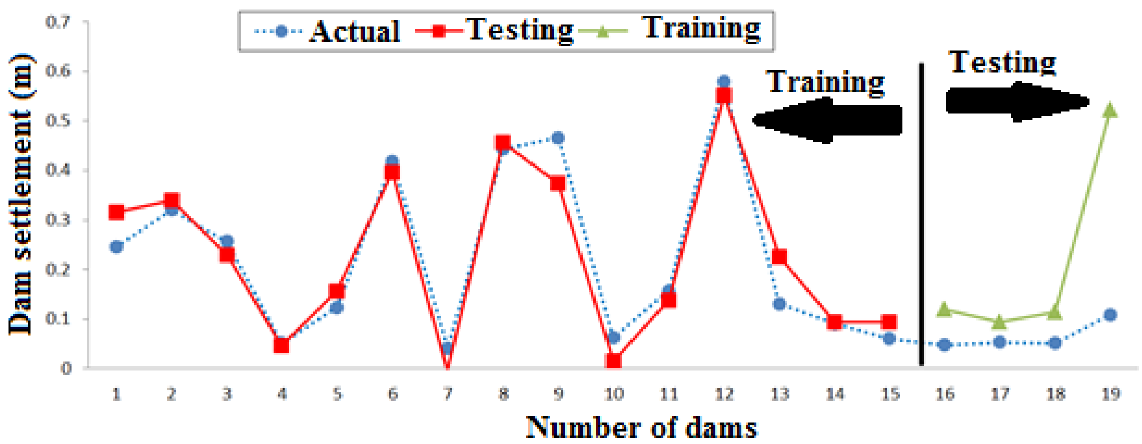

Fig. 3. Compression of actual and GEP predicted settlement of sloping core rockfill dam (for Eq. (4)) in two data sets (training and testing phases)

Unlike the GEP, other soft computing methods do not provide a specific equation and it is applicable only in MATLAB software as coding. It will not be used for future purposes as much as GEP equations. Since the correlations provided by GEP method seem to be complicated, a program was designed for computation using Visual Basic (VB). A form has been prepared for entering the inputs. In fact, the purpose of designing this form is to facilitate the computation of correlations. Fig. 4 shows the form.

Here is an example of how to work with this form; first, two parameters must be entered in the desired locations. As shown in Fig. 5, two outputs are displayed in this form. Totally, it can be said that the presented equations in this paper predict the settlement of this kind of dams (S_{SC}) with high accuracy because they have a suitable number of input parameters.

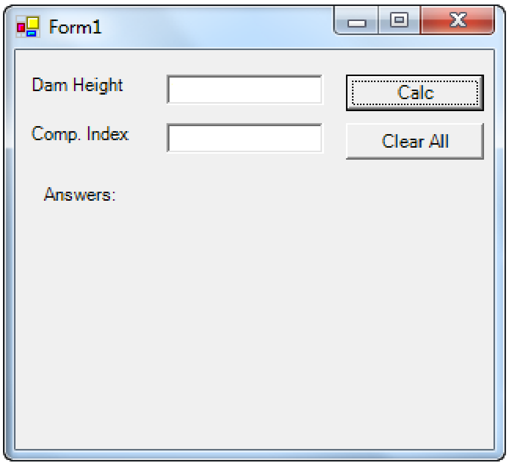

Fig. 4. A profile of the form for prediction of dam settlement

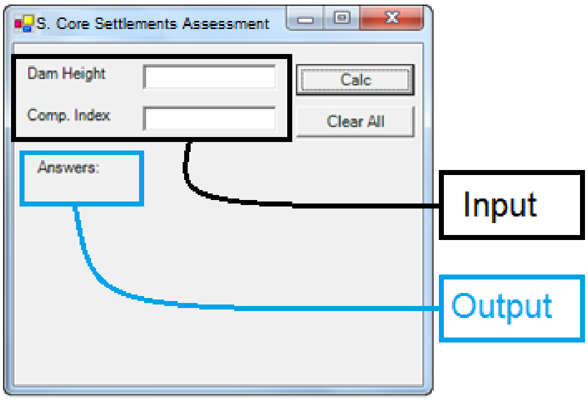

Fig. 5. An example for prediction of dam settlement

IV. Conclusion

The GEP method was used to predict the settlement of rockfill dams with sloping core. Parameters such as the height of the dam (H) and dam compressibility index (C_i) were taken to be input parameters. The data from 19 dams were used. For GEP, the data were divided into training (15/19) and testing (4/19) sets. The results from soft computing method (GEP) were satisfactory. A simulation has been done based on Visual Basic (VB) software to estimate the settlement. Using this model, the dam settlement can be easily predicted employing the correlations obtained from GEP by only the desired inputs. Finally, according to the results of the present study, it is worthy to note that the intelligent methods are useful tools for solving problems with complex mechanisms. The equations can be intelligently generalized to new data. The present models can be used for future purposes to estimate the settlement of rockfill dams with sloping core.

References

[1]. Habibagahi, G., (2002). "Post-Construction Settlement of Rockfill Dams Analyzed via Adaptive Network-based Fuzzy Inference Systems." Computers and Geotechnics, 29, pp. 211–233.

[2]. Fell, R., MacGregor, P., Stapledon, D., and Bell, G. (2005). Geotechnical Engineering of Dams, Taylor & Francis Group plc., London, UK.

[3]. Chen, Y., Hu, R., Lu, W., Li, D., Zhou, C., (2011). Modeling coupled processes of non-steady seepage flow and non-linear deformation for a concrete-faced rockfill dam, Computers and Structures, doi: 10.1016 / j. compstruc . 2011.03. 012.

[4]. Han-Gyu, P., Yong-Seong, K., Min-Woo, S., Heui-Dae, L., (2005). Settlement Behavior Characteristics of CFRD in Construction Period- Case of Daegok Dam, Jour. of the KGS, Vol. 21, No. 7, pp. 91-105.

[5]. Savas, Ö. R., (2005). Settlement Behavior of Concrete Faced Rockfill Dams: A Case Study, A thesis submitted to the graduate school of natural and applied sciences of Middle East technical university.

[6]. Woo-Seo, M., Ha, I., Kim, Y.S., Olson, S. M., M-Asce, P.E., (2009). Behavior of Concrete-Faced Rockfill Dams during Initial Impoundment, JOURNAL OF GEOTECHNICAL AND GEOENVIRONMENTAL ENGINEERING © ASCE / AUGUST 2009, pp. 1070-1081.

[7]. Behnia D., Ahangari K., Noorzad A., Moeinossadat SR., (2013). Predicting crest settlement in concrete face rockfill dams using adaptive neuro-fuzzy inference system and gene expression programming intelligent methods. Journal of Zhejiang University-SCIENCE A (Applied Physics & Engineering) 14(8):589-602. doi: 10.1631/jzus.A1200301.

[8]. Behnia D., Shahriar K., (2015). Prediction of Tunnelling-induced Settlement Using Gene Expression Programming, American Rock Mechanics Association (ARMA2015), 49th US Rock Mechanics / Geomechanics Symposium, San Francisco, CA, USA.

[9]. Cetin, H., Laman, M., and Ertunc, A. (2000). "Settlement and Slaking Problems in the World's Fourth Largest Rock-fill Dam, the Ataturk Dam in Turkey." Engineering Geology, 56, pp. 225–242.

[10]. Gikas, V., and Sakellariou, M. (2008). "Settlement analysis of the Mornos earth dam (Greece): Evidence from numerical modeling and geodetic monitoring." Engineering Structures, 30, pp. 3074–3081.

[11]. Ozkuzukiran, S., Ozkan, M.Y., Ozyazicioglu, M., and Yildiz, G.S. (2006). "Settlement Behaviour of a Concrete Faced Rockfill Dam." Geotechnical and Geological Engineering, 24, pp. 1665–1678.

[12]. Zhou, W., Hua, J., Chang, X., and Zhou, C. (2011). "Settlement Analysis of the Shuibuya Concrete-Face Rockfill Dam." Computers and Geotechnics, 38, pp. 269–280.

[13]. Seong Kim, Y., Tak Kim, B., (2008). Prediction of Relative Crest Settlement of Concrete-Face Rockfill Dams Analyzed using An Artifical Neural Network Model, Computer and Geotechnics, 35, pp. 313-322.

[14]. Clements, R.P. 1984. Post-Construction Deformation of Rockfill Dams, J. of Geotechnical ASCE, Engineering, Vol. 110, No. 7, pp. 821–840.

[15]. Lawton FL, Lester MD. 1964. Settlement of rockfill dams. Proceedings of the 8th International Congress on Large Dams, Vol. 3, Edinburgh, UK, pp. 599–613.

[16]. Soydemir C, Kjaernsli B. 1979. Deformation of membrane faced rockfill dams. Proceedings of the 7th European Conference on Soil Mechanics and Foundation Engineering, Vol. 3, Brighton, UK, pp. 281–284.

[17]. Kayadelen C (2011) Soil liquefaction modeling by Genetic Expression Programming and Neuro-Fuzzy, Expert Systems with Applications. 38,4080–4087.

[18]. Teodorescu L, Sherwood D (2008) High energy physics event selection with gene expression programming, Computer Physics Communications. 178,409-419.

[19]. Sivanandam SN, Deepa SN (2008) Introduction to Genetic Algorithms Springer-Verlag Berlin Heidelberg.

[20]. Koza J (1992) Genetic programming on the programming of computers by means of natural selection, Cambridge (MA): MIT Press.

[21]. Mollahasani A, Alavi AH, Gandomi AH (2011) Empirical modeling of plate load test moduli of soil via gene expression programming, Computers and Geotechnics. 38,281–286.