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Settlement modeling in central core rockfill dams by new approaches

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ABSTRACT

One of the most important reasons for the serious damage of embankment dams is their impermissible settlement. Therefore, it can be stated that the prediction of settlement of a dam is of paramount importance. This study aims to apply intelligent methods to predict settlement after constructing central core rockfill dams. Attempts were made in this research to prepare models for predicting settlement of these dams using the information of 35 different central core rockfill dams all over the world and Adaptive Neuro-Fuzzy Interface System (ANFIS) and Gene Expression Programming (GEP) methods. Parameters such as height of dam (H) and compressibility index (C_i) were considered as the input parameters. Finally, a form was designed using visual basic software for predicting dam settlement. With respect to the accuracy of the results obtained from the intelligent methods, they can be recommended for predicting settlement after constructing central core rockfill dams for the future plans.

1. 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. Therefore, stability of dams has particularly attracted the attention of the engineers who design these structures, especially in recent decades. One of these structures is the rockfill dam which is constructed with the optimum use of local materials. Generally, these dams are constructed in places where there is a sufficient amount of rock material and the basement rock has a favorable quality. The common rockfill dams include concrete-faced or asphalt-faced rockfill dams and impervious central core rockfill dams. This paper discusses settlement of impervious central core rockfill dams.

Serious losses to rockfill dams with impervious and clay cores include the creation of piping in the core, creation of diagonal, horizontal and perpendicular cracks in the core, loss of free board due to high settlement, unequal and high displacement of upstream membranes and high leakage of water. It can be stated that one of the major common factors in serious damage of rockfill dams is the impermissible settlement of their crest and bodies, which causes cracks to form along the body and the heel of the dam downstream. These cracks lead to an increase in flow rate in drains in the heel of the dam and generally will cause heel instability and dam destruction [1]. In most dams, crest settlement is unequal; however, it might be symmetrical because dam load is maximal at the axial section and reaches zero at the toe. The effect of unequal settlement, even if symmetrical, is not negligible in different sections of a dam. Under normal conditions, the permissible settlement of a dam caused by the settlement of its body can be considered as about 2% of the structure height. In earthquake-prone areas, 1% is added to this amount due to earthquake effects [2]. Therefore, an appropriate estimation of settlement after construction is required to supervise the performance of the dam and to warn design 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 is stated above, predicting the settlement of a dam is extremely important.

In most of the studies, usually one or several dams were studied in a particular and limited manner [3–11]. A few relations have been presented in this case and one of the most noticeable relations is that offered by Clements. He studied the settlement of the crests of 68 rockfill dams after construction and proposed an equation based on his findings: ($S = aH^b$) [12]. The relations presented by Lawton and Lester [13] and Soydemir and Kjaernsli [14] can also be mentioned. 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. The soft calculation

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method can be used to overcome such constraints and to provide a simpler and more accurate method. These methods have no limitation in applying further effective parameters. In the present research, two modern and intelligent methods of Adaptive Neuro-Fuzzy Interface System (ANFIS) and Gene Expression Programming (GEP) are used, which are the methods 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.

2. Study of database

The present paper uses the information of 35 central core rockfill dams. The information on these dams was collected from earlier studies among the available documents [15]. Table 1 presents the full specifications of these dams. Several parameters, such as height of dam, condition of the foundations, dam shape, duration of impounding and geo-mechanical parameters of rockfills are considered to be influential in settlement. All of the available relations in predicting settlement of embankment dams depend on a single-factor, namely the dam height. Only the two parameters, dam height and dam compressibility index, are common in all dams. Two input parameters were used for predicting settlement after constructing central core rockfill dams; they include dam height (H) and compressibility index (C_i). The compressibility index (C_i) indicates the general compression of a dam which is calculated by considering the earth-filling compression method and quality of foundation materials. This parameter is obtained as Eq. (1) [15]:

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

where i_E and i_F are the indices of the quality of earth-filling compression and foundation, respectively. These indices vary between 0 and 1. The proposed values for these indices are shown in Tables 2 and 3. It should be noted that there is not sufficient information about construction method, earth filling, and foundation materials of some dams. In these cases, an average amount of compressibility index was used as an alternative.

Table 4 shows the range and complete information of each parameter. Fig. 1a and b shows the correlation of two input parameters (H and C_i) compared to the dependent parameter (S). In addition, Fig. 1c shows the dispersion of dam settlement. To make intelligent models, the data were divided into two groups of training and testing. Out of the 35 sets of data, 28 sets of the data (80%)

Table 2
Embankment compaction index [15].

Compaction method	Lift thickness (m)		
	<2.00	2.00–3.00	>3.00
Compacted with roller	1.00	0.50	0.25
Dumped, sluiced	0.20	0.15	0.10
Dump, not sluiced	0.10	0.05	0.00

Table 3
Foundation quality index [15].

Sound bedrock	Poor or weathered bedrock	Thick riverbed deposit (>10.0 m)
1.0	0.5	0.1

Table 1
Specifications of some central core rockfill dams used in this study [15].

No.	Dam name	Dam height (m)	Dam compressibility index (C_i)	Total settlement (m)	Application type
1	Akosombo	112.8	0.9	0.649	Training
2	Ambuklao	128.5	0.8	0.810	Training
3	Beas	132.5	0.3	0.413	Training
4	Cherry Valley	100.6	0.9	0.138	Training
5	Dhunn Valley	35.0	0.5	0.066	Training
6	El Infiernillo	148.0	0.6	0.462	Training
7	Estreito	97.0	0.0	0.049	Training
8	Gepatsch	153.0	0.8	1.240	Training
9	Messaure	101.0	0.8	0.012	Training
10	Mud Mountain	122.0	0.9	0.580	Training
11	Notteley	56.1	1.0	0.175	Training
12	Preuca	60.0	1.0	0.255	Training
13	Presidente Aleman	75.0	0.9	0.133	Training
14	South Holston	86.9	1.0	0.608	Training
15	Tooma	68.0	0.9	0.059	Training
16	Watauga	96.8	1.0	0.471	Training
17	Outardes 4 dam 1	122.0	0.0	0.171	Training
18	Outardes 4 dam 3	25.0	0.0	0.023	Training
19	LG2 Main Dam	168.0	0.0	0.420	Training
20	LG2 Dyke D5	66.0	0.0	0.092	Training
21	LG2 Dyke D7	55.0	0.0	0.036	Training
22	LG2 Dyke D8	30.0	0.0	0.020	Training
23	LG3 North Dam	93.0	0.0	0.093	Training
24	Caiapiscau KA3	54.0	0.0	0.027	Training
25	Caiapiscau KA5	47.0	0.0	0.028	Training
26	Laurel	90.0	0.0	0.090	Training
27	LG3 South Dam	93.0	0.0	0.130	Training
28	Netzhualcoyotl	137.5	0.3	0.429	Training
29	Kajakai	100.0	0.9	0.040	Test
30	Cupatizio	72.4	0.9	0.091	Test
31	High Aswan	111.0	0.8	0.122	Test
32	Llyn Brianne	91.0	0.5	0.146	Test
33	Outardes 4 dam	110.0	0.0	0.099	Test
34	Hyttejuvet	93.0	0.9	0.177	Test
35	Muddy Run	76.2	0.9	0.267	Test