

sensitivity analysis of influence factors on discharge coefficient of short throat shaft spillway by utilizing artificial neural network. (Case study: physical model of saint Louis forebay)

Abstract

The shaft spillway is simply a closed conduit in which the flood flow is carried rapidly from a high to a low elevation. This spillway can be used advantageously at dam sites in narrow canyons where the abutments rise steeply or where a diversion tunnel or conduit is available as the downstream leg. Another advantage of this type of spillway is that near-maximum capacity is attained at relatively low heads. This characteristic makes the spillway ideal for use where the maximum spillway outflow is limited. In this study by utilizing nearly 300 data that comes from Laboratory tests of different conditions of morning glory spillway, hydraulic parameters such as Froude number, submergence ratio, dimensionless parameters like effective of vortex breaker shape and number of vortex breaker received, then by use of these parameters accurate equation for discharge coefficient received. Using these parameters in the artificial neural network defines each parameter's impact and importance. The criterion for choosing the most important factor in this study is a root-mean-square error (RMSE). The results show that the number of vortex breakers has more effect on the discharge coefficient, and by omitting this parameter, a maximum error (2.154) occurred.

Keywords: *levenberg-Marquardt-algorithm, Sensitivity analysis, artificial neural network, shaft spillway, discharge coefficient.*

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1. Introduction

A shaft spillway is a type of spillway that can use instead of a side wier . Another advantage of this type of spillway is that near-maximum capacity is attained at relatively low heads. This characteristic makes the spillway ideal for use where the maximum spillway outflow is limited. For this reason, they are most suited where temporary storage space in the reservoir is large enough to significantly attenuate the incoming flood. The principal elements of a shaft spillway are an intake, including the spillway crest, the transition from the crest to the shaft, the bend and the downstream leg, and a tunnel and energy dissipater, as shown in Figure 1. [1]. Mousavi Jahromi et al. (2007) have studied the effects of vortex breakers on the discharge coefficient. The results showed that using 3 vortex breakers increases the discharge coefficient significantly. They also have suggested utilizing 30 and 60 degrees for installing vortex breakers since it is more efficient. Bagheri et al. (2013) studied the physical model of the shaft spillway, and 108 tests were done. Utilizing linear regression offered the equation for discharge coefficient, which included the effect of submergence ratio:

$$Cd = .1765 \left(\frac{H}{D}\right)^{-1.718} \quad (1)$$

Mousavi and Aalavi (2015) have studied the roughness of conduits of spillways. Their results showed that if the head of water exceeds the head of design, the discharge coefficient increases. Fattahi et al. (2012) have studied the physical model of shaft spillway and installed 3 and 4 vortex breakers in different conditions of Crest diameter, which have been changed in 3 values. Their studies showed that installing 3 vortex breakers increases the discharge coefficient. Aghamajidi et al. (2014) studied the saint Louis forebay dam and investigated on flow over the spillway. They surveyed different situations of flow under the effects of vortex breakers, several vortex breakers and some stairs; then, by utilizing linear regression, they achieved the formulation that included Froude number, submergence ratio and dimensionless parameters, which showed the effects of the number of vortex breakers, type of vortex breakers and number of stairs. The formulation that they offered for discharge coefficient:

$$Cd = a \left(\frac{H}{Rs}\right)^b (Fr)^c d \quad (2)$$

This current study utilizes the results from the saint Louis fore bay physical model.

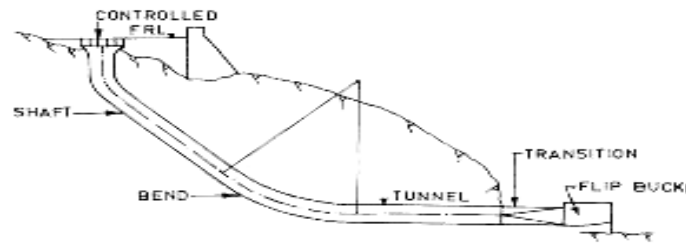


Fig1: Elements of a shaft spillway.

Afshar et al. (2007) investigated the optimization of designing the surface water collection network. Dehghan et al. (2014) addressed the economic optimization of the deviation system using a genetic algorithm, and they could obtain the minimum tunnel diameter and reduce the time for tunnel construction. Ahadian (2015) analyzed the sensitivity of the effective factors on aeration using fuzzy neural network and artificial neural network methods. They obtained a significant amount of each parameter effective on aeration. Asghari et al. (2008) estimated hydraulic parameters affecting the unconfined aquifer using a genetic algorithm. Soltani et al. (2011) investigated effective factors on pipe failure rate in water distribution networks using a mix of the artificial neural network and genetic algorithm. Aslani et al. (2014) determined the values of the genetic algorithm parameters for optimizing concrete gravity dams. They obtained the best values for replication rate, the initial population, the mutation rate, and the selection rate. Fattor et al. (2001) discussed the onset of submersion in the morning glory spillway and showed that this state is unstable and severe, leading to serious pressure fluctuations. Khatsuria (2005) conducted several studies on pressure, submersion ratio, and discharge coefficient of smooth spillways. Prof. B.S. Thandaveswara (2004) studied the stepped morning glory spillway model to obtain hydraulic parameters of the model compared with the main spillway and created some relationships between them. He also evaluated discharge effects by changing the height of the steps. Aghamajidi et al. (2013) tried to study the effect of vortex breaker and steeped chamber on the morning glory spillway. He found out the vortex breaker greatly affects the discharge coefficient and also tried to formulate the effective emptying coefficients of short through shaft spillway. Other factors affecting vortex formation include insufficient submergence, current separation, a sudden change in the flow direction, and velocities above 0.6 m/s in the approaching flow field (Salmasi, 2003). Razavi et al. (2017) investigated the numerical modeling of flows in morning glory spillways using Flow3D. The results show that the increased suspended load reduces the current passing through the spillway, while the dead load values depend on the suspended load. Bagheri et al. (2010) conducted a hydraulic investigation of the labyrinth morning glory spillway. The experimental results showed that the use of a multidimensional spillway increases the discharge

capacity and spillway discharge coefficient. Musavi Jahromi (2016) investigated the discharge coefficient of morning glory spillways with the longitudinal angle of the vortex breaker. The results showed that the 45-degree angle of the vortex breaker on the spillway increased the discharge coefficient. Sayadzadeh et al. (2020) investigated the effect of pyramidal vortex breakers on the discharge capacity of the morning glory spillway. The results showed that placing a hexagonal group of vortex breakers caused a significant increase of approximately 51% in the discharge coefficient at the spillway crest control section and an increase of approximately 16% in the morning glory spillway. Morning glory spillway is used in the reservoir dams in narrow valleys and many locations with high slopes in reservoir walls. Its main advantage is the high capacity in passing the discharge created in low losses. This characteristic makes the performance of such spillways useful for discharges less than the designs. Thus, morning glory spillways are the ideal structure for passing discharges in situations where there is enough time for temporary storage in the reservoir to reduce the intensity of the next flood. The genetic algorithm model is the perfect optimization method inspired by nature. These algorithms are based on natural biological evolution. Since the early 1980s, genetic algorithms have published many articles to confirm the method of optimizing functions. In structure engineering, S.Rajeer, C.S.Krishnamoorthy, and P.Hajela showed that a genetic algorithm is the best method for optimizing structures using discrete variables. [Marler (2004)].

Artificial Neural Network[3]

An Artificial Neural Network (ANN) is an information-processing paradigm inspired by how biological nervous systems, such as the brain, process information. The key element of this paradigm is the novel structure of the information processing system. It comprises many highly interconnected processing elements (neurons) working in unison to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process. Learning in biological systems involves adjustments to the synaptic connections between the neurons. This is true of ANNs as well. An artificial Neural Network is a system loosely modeled on the human brain. The field goes by

many names, such as connectionism, parallel distributed processing, neuro computing, natural intelligent systems, machine learning algorithms, and artificial neural networks. It attempts to simulate the multiple layers of simple processing

elements called neurons within specialized hardware or sophisticated software. Each neuron is linked to certain of its neighbors with varying coefficients of connectivity that represent the strengths of these connections.

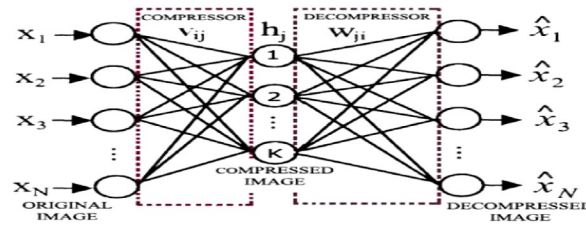


Fig2: Basic compression structure

Neural networks, with their remarkable ability to derive meaning from complicated or imprecise data, can learn and detect trends that are too complex to be noticed by humans or a trained neural network can be thought of as an "expert" in the category of information it has been given to analyze. This expert can then use to provide projections given new situations of interest and answer "what if" questions. The advantages include Adaptive learning, Self- Organization, Real Time Operation, and Fault Tolerance via Redundant Information Coding.

This study has been inspired by the physical model of the Saint Louis Forebay dam spillway in the central valley of California, America. This model, the dimensions of which have been presented in figures (1, 2), is constituted of a 1000-liter reservoir upstream (including the body of the dam, spillway and water canal), a right angle, a tunnel for transferring the spillway's water to downstream, a 2000-liter reservoir in downstream of the water transfer tunnel and a pump for water suction from the downstream reservoir to the upstream one. In this experimental model, the spillway body, including five

(dimensions types of spillways with completely different designs is devised in the upstream reservoir (figures 3 to 7). The surface arc on two sides of the body of all spillways follows the same equation. Besides, the dimensions of all spillways are the same, but the internal surface of each spillway is different from the other. The first type of spillway has a smooth surface and the spillways of the second to the fifth type have eleven-step, six-step, four-step and three-step surfaces. The height of each step is h , and the width of each step is b . For a smooth spillway, it has been supposed that the height and width of each step are very small and similar to each other. For the spillways of the second to the fifth type, the height of each step is continuously changing, and each step's width is fixed. In the eleven-step, six-step, four-step and three-step spillways, one, two, three and four holes are made respectively on a specific section on each step for calculating water height equivalent to pressure. In the smooth spillway, the location of holes is considered the same as that of the holes of the eleven-step spillway; therefore, the total of holes in spillways of types one to five is 11, 11, 10, 9 and 9 in this regard. The number of holes indicates the number of Froude number and h/b ratios we require in order to be able to compare the spillways' surfaces with each other.

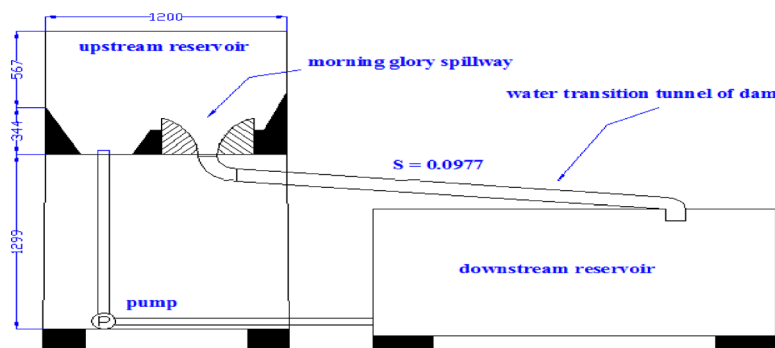


Fig. 3: Cross section of the physical model (dimensions based on millimeter)

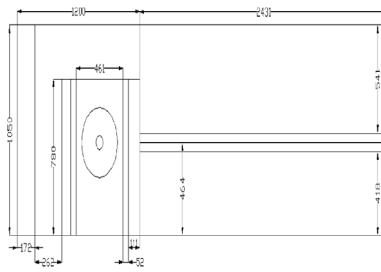


Fig. 4: Top view of the physical model (dimensions based on millimeter)

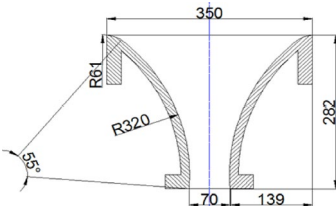


Fig. 5: a model of a smooth spillway (1/50 of saint Louis ferbay spillway)

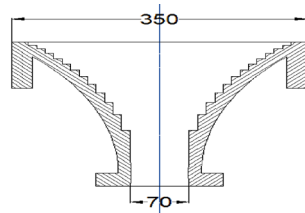


Fig. 6: a model of an eleven-step spillway

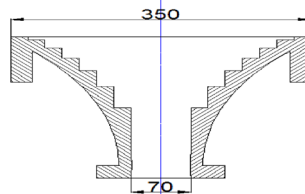


Fig. 7: a model of a six-step spillway

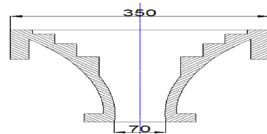


Fig. 8: a model of a four-step spillway

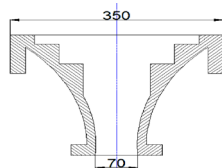


Fig. 9: a model of a three-step spillway

(Dimensions of all spillways are based on millimeters)

equivalent to fluid pressure at that specific point using a Piezometer pipe. (It is to be mentioned that the Piezometer pipe is the most accurate fluid pressure measurement instrument)[2].By doing 300 tests in discharge between 2 to 3 cube meters per second on 46 different types of spillways, submergence ratio and Froude number were obtained using linear regression and SPSS software, and equation(2) was obtained. This equation is obtained with the aid of dimensional analysis based on the Buckingham theory includes 6 dimensionless parameters. Parameter a expresses the effect of the number of vortex breakers, d expresses the type of vortex breakers and b and c are exponent parameters used in the Buckingham theory. Due to this principle that the value of discharge coefficient should be between .08 to 2.25, first with submergence ratio and Froude number and utilizing NSGA-II the values of a,b,c,d calibrated according to discharge coefficient that achieved from tests, by using calibrated values, data sheet were built, Then by omitting method of one parameter and modeling based on other parameters error rate calculated. The parameter which has the maximum error rate is the most important. Estimating error rate in calculations for defining pattern and structure with minimum error rate for

predicting discharge coefficient. Therefore, the root-mean-square-error (RMSE) was used to survey the model's reliability. RMSE equation is explained below:

$$RMSE = \sqrt{\frac{\sum_{k=1}^N (C_k - M_k)^2}{N}} \quad (3)$$

In this equation, C_k is the calculated value, M_k is the measured value, and N is the number of data.

RESULTS AND DISCUSSION:

First, by utilizing the artificial neural network toolbox, some parameters were used as inputs data which include 6 dimensionless parameters that are achieved from Lab and Genetic algorithm defined and target point was defined as discharge coefficient. After this step, the percentage of trained data is defined. The percentage used for trained data is 70%, then the number of hidden neurons has been defined. By trial and error, the best value for the number of hidden neurons is 10. In the next step, the network has been made; after that, the network has been trained based levenberg-marquardt algorithm method.

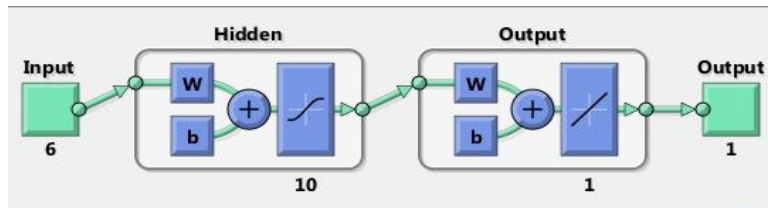
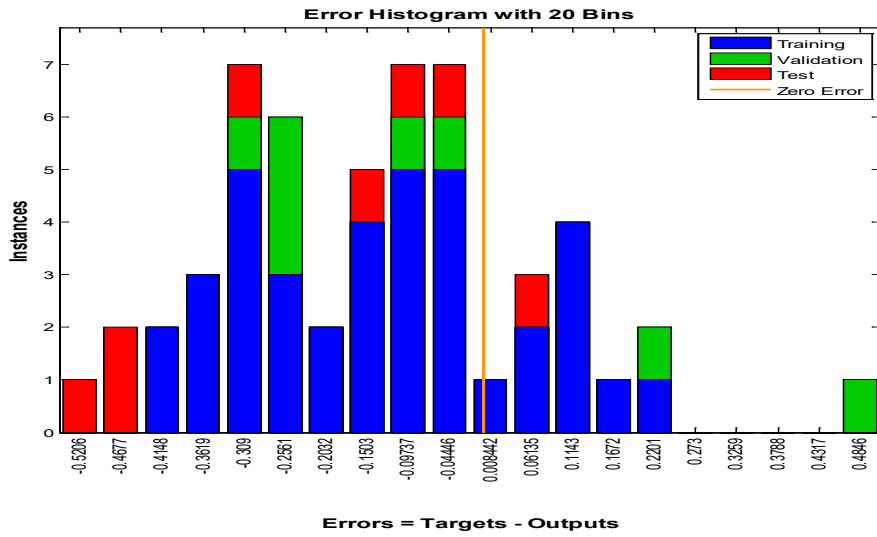
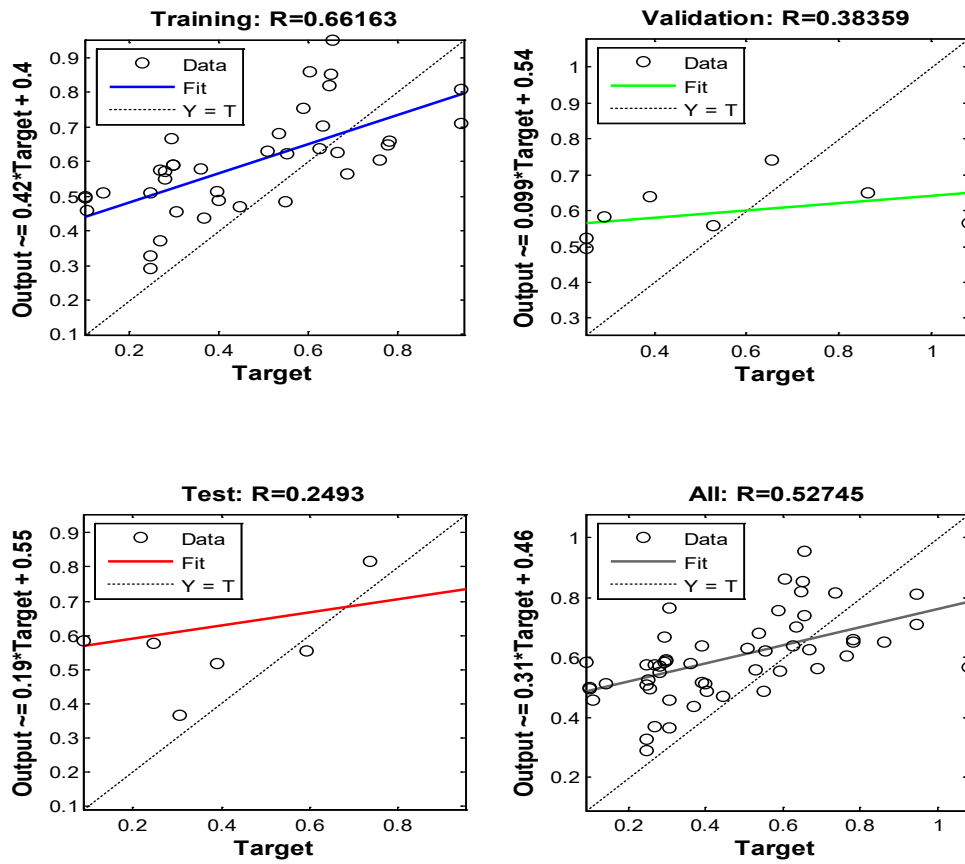


Fig10: ANN structure for the first calculation.

Using cumulative errors, the Importance percentage of each parameter was obtained as shown in fig 12.



Figs 11: results by omitting parameter a



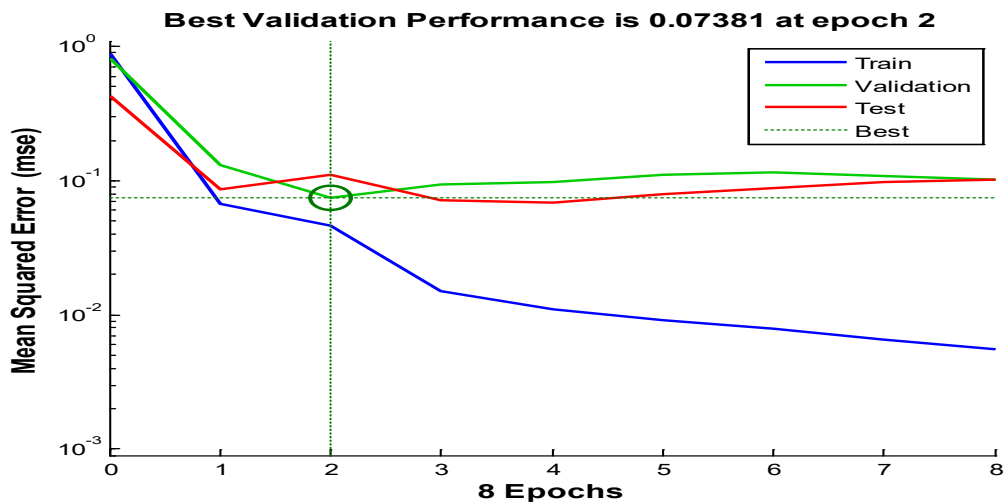


Table1. the error rate of all parameters in ANN

| Sensitivity method | RMSE | MSE | R | Inputs | Omitted parameters |
|--------------------|--------|----------|--------|------------------|--------------------|
| ANN | .01129 | .0012476 | .8848 | H/Rs,Fr,a,b,c,d | _____ |
| ANN | .1375 | .018913 | .80186 | Fr, a ,b ,c ,d | Submergence ratio |
| ANN | .1898 | .036032 | .72537 | H/Rs ,a, b, c ,d | Froude number |
| ANN | .2154 | .04644 | .52745 | H/Rs,Fr,b,c,d | Parameter a |
| ANN | .0587 | .003352 | .8725 | H/Rs,Fr, a ,c ,d | Parameter b |
| ANN | .07963 | .0063422 | .82836 | H/Rs,Fr,a ,b, d | Parameter c |
| ANN | .134 | .01797 | .85581 | H/Rs,Fr,a,b,c | Parameter d |

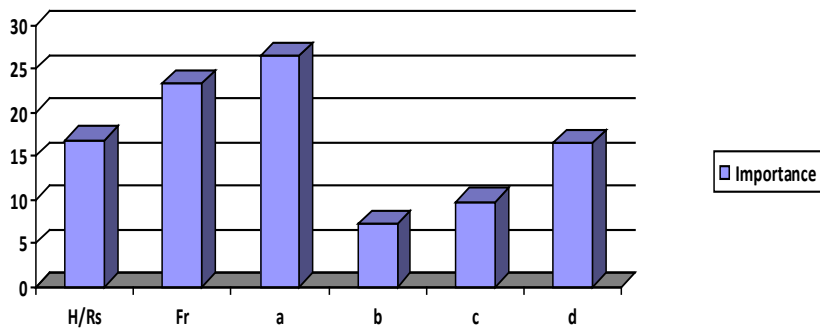


Fig12: the importance percentage of each parameter in Cd.

CONCLUSION:

The discharge coefficient is one of the most important hydraulic parameters for designing a shaft spillway. This parameter has included effective parameters such as submergence ratio and Froude number. In this study, after defining the value of effective factor d, sensitivity rates of discharge coefficient were measured. The most important factor that has maximum sensitivity in Cd is parameter a, defined as the number of vortex breakers.

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