Effect of geometric specifications of ogee spillway on the volume variation of concrete consumption using genetic algorithm

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Abstract.- Nature is a great inspirational source of complex and interesting phenomena that can be used to solve current problems. Genetic algorithm is one of the nature-inspired meta-initiative algorithms that can play an important role in optimizing engineering. The purpose of this research is to achieve a relation to determine the volume of concrete used in the ogee spillway. With the help of genetic algorithm, optimization was performed in MATLAB software. The ratio of the volume of concrete used in the ideal spillway over P/H (height/head) was determined and finally the relation between W/P (width of the spillway and its height at the cross section) was reported with the volume of concrete consumption in the spillway. Using a regression model, a new relation was reported for two volumes of concrete consumption and geometric component (W/P). The results of the research indicated that there is linear and direct relation between (W/P) with concrete volume. By choosing the optimal width (W) to spillway height (P), it saves a significant amount at the cost of concrete and operation.

Keywords: spillway geometry; concrete volume; genetic algorithm; ideal spillway.

Efecto de las especificaciones geométricas de un aliviadero ogee en la variación del volumen de consumo de hormigón utilizando algoritmo genético

Resumen.- La naturaleza es una gran fuente de inspiración de fenómenos complejos e interesantes que pueden usarse para resolver problemas actuales. El algoritmo genético es uno de los algoritmos de meta-iniciativa inspirados en la naturaleza que pueden desempeñar un papel importante en la optimización de la ingeniería. El propósito de esta investigación es lograr una relación para determinar el volumen de concreto utilizado en el aliviadero de ogee. Con la ayuda del algoritmo genético, la optimización se realizó con el software MATLAB. Se determinó la relación del volumen de concreto utilizado en el aliviadero ideal sobre P/H y finalmente se reportó la relación entre W/P (ancho del aliviadero y su altura en la sección transversal) con el volumen de consumo de hormigón en el aliviadero. Usando un modelo de regresión, se reportó una nueva relación para dos volúmenes de consumo de hormigón y W/P. Los resultados de la investigación indicaron que existe una relación lineal y directa entre el ancho y la altura del aliviadero (W/P) con el volumen de concreto. Al elegir el ancho óptimo (W) para la altura del aliviadero (P), se obtiene un ahorro significativo en costo de concreto y en operación.

Palabras clave: geometría del aliviadero; volumen de concreto; algoritmo genético; aliviadero ideal.

Received: April 05, 2019.
Accepted: June 10, 2019.

1. Introduction

For excess water and floods from the mirage to the dams, an instrument called the spillway is used. Spillways are made for a variety of purposes, among which the most important are the passage of excessive flood water, the flow of excess streams on the capacity of the riverbeds, the raising and stabilization of the level of water to enter diverse cities, the adjustment of slopes of the reservoirs by the construction of successive spillways and Measurement Dedicated. Due to the sensitivity of the work being done by spillways, strong, reliable and high-performance devices must be built that can be ready for productivity at any time spillways

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can be divided into two general superficial groups (graft, lateral, congress and steppe) and subsurface (for example morning glory spillway) [1].

Several studies have been made on direct-link gradient spillways. From 1886 to 1888, a comprehensive laboratory research have been conducted to determine the shape of a blade of water on a sharp edges, and carried out the first study on the shape of the spillway curve by [2]. The extensive experiments carried out by USBR, (1976) [3] from 1932 to 1948 on the profile of a sharp edge spillway blade for different slopes of the upper wall spillway, subsequently, USACE [4] introduced several states standard for crosslinking spillway.

Since the 1960s, researchers have been trying to simulate and solve experimental research with numerical methods [5]. The apparent flow characteristics were examined on diagonal spillways. They provided a new relation for calculating the flow in these types of spillways, so that this relation is in good agreement with laboratory values. Harcheghani *et al.*[1] by studying the physical sample of the Arctic spillway of the Garmi dam, the teeth examined the effective measurements of the coefficient of this spillway and provided relationships for calculating the flow coefficient in this spillway. Date *et al.*[6] stated that ogee spillway due to the proper hydraulic properties is one of the most popular hydraulic structures in scientific studies. Engineers widely use this type of spillway due to the hydraulic characteristics.

The proper characteristics of this type of spillway are effective drainage and high accuracy in discharge measurement. In general, hydraulic structures such as spillways require extraordinary high precision in optimization and design. Hydraulic structures are often complex and require attention in many cases so that the flow behavior around hydraulic structures and their effects in the environment can be accurately predicted [7]. The main function of the ogee spillway is to create conditions for the safe flow of flood from upstream to downstream. Inappropriate design and inadequate capacity of spillways have damaged some of the dams.

Therefore, the spillway must be appropriately hydraulic and structural. Bagatur and Onen used gene expression planning (GEP) models as an alternative approach to predict apparent features and spillway design coefficients and suggested a new relation for this type of spillway [8]. The performance of GEP was very well evaluated in comparison with the regression model in predicting ogee spillway characteristics.

In this research, a definition of ideal ogee spillway is presented at first. Then, relationship between the volume of concrete used in constructing an ideal spillway over P/H (height ratio to overhead design) was determined. Finally, the relationship between W/P (width of the spillway to its height) and the volume of concrete used in the spillway was reported. In this study, the width of the spillway (W) is the horizontal distance between the spillway crown and the downstream and differs with the definition of the spillway length (L).

The results of this research are of great importance to spillway structure designers and researchers. The relationship between geometric spillway and volume of concrete consumption is one of the important issues in the field of hydraulic structures. In the present study, with consideration of the ideal spillway, the minimization of the amount of concrete used in the spillway structure has been made; which will help to reduce the cost of making it. The objectives of this research include:

1. Minimizing the amount of concrete used in the construction of a cliff spillway.
2. Determining the equation for the concrete volume in the ideal spillway.
3. Determining the relation between W/P (the width of the spillway to its height) with the amount of concrete used in the spillway.

2. Methodology

For the design and construction of an ogee spillway, various components are considered, some of which are shown in Figure 1. The relationships between these components are often derived from empirical experiments. These relationships were common in the mid-20th century and were developed by North American research and engineering institutes. For spillway, equation (1) is one of the most well-known relations that correlates geometric components with the discharge and crown load.

$$Q = CLH^{3/2} \tag{1}$$

In equation (1), Q is expressed in terms of (m³/s) and C is the discharge coefficient. It depends on the spillway geometric design, upstream flow conditions, and others metrics [9]. The component L is the spillway length and H is the head which are expressed in terms of meters. H in the following equation includes two static components on the crown and a height such as velocity. According to equation (2), the design load on the spillway is equal to the total static load (Hp) and the equivalent height (Ha)

$$H(Design) = Hp + Ha \tag{2}$$

2.1. Ideal spillway

The most common and perhaps the cheapest spillway that can handle a lot of water is the linkage spillway. Many researchers have tried to obtain equations based on the direction of motion of a water particle for the flow axis.

$$\frac{y}{H} = 0.15 + 0.055\left(\frac{x}{H}\right) - 20.425\left(\frac{x}{H}\right)^2 \tag{3}$$

Equation (3) is provided by Blaisdell [10]. X is the horizontal component of the flow of water on the spillway and y is the vertical component of the flow of water. H in the equation (2) includes two static load components on the crown and a height such as velocity. The overall shape of the ogee spillway is shown in Figure 1. In the ogee spillway research, two geometric components are often investigated: the length and height of the spillway. In this study, the effect of length is not considered and the basis of minimization is based on the volume of concrete used per length. The width of the spillway (W) is the same as final value of horizontal component (x) in Figure 1 for the peak overshoot.

If a concrete spillway is made just like the bottom curve of the mass flow, an ideal spillway will be

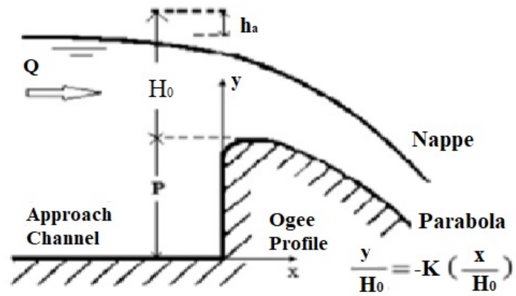


Figure 1: Flow over and ogee spillway [11]

achieved and the pressure on the spillway crown will be equivalent to atmospheric pressure. In this case, if the static load increases on the spillway crown; due to destruction of the mass flow, the pressure on the crown is negative and it will cause shaking and corrosion. Conversely, if the static load of water on the crown of spillway decreases, the mass flow falls on the spillway body and creates some additional friction that increases the friction as a result of the energy loss. Considering that H is considered for discharge, the second mode is most likely to occur. Some sources refer to the WES spillway or standard spillway and its shape is similar to the Figure 1.

In this study, we consider the ideal spillway equivalent to the standard spillway (WES) (Figure 2).

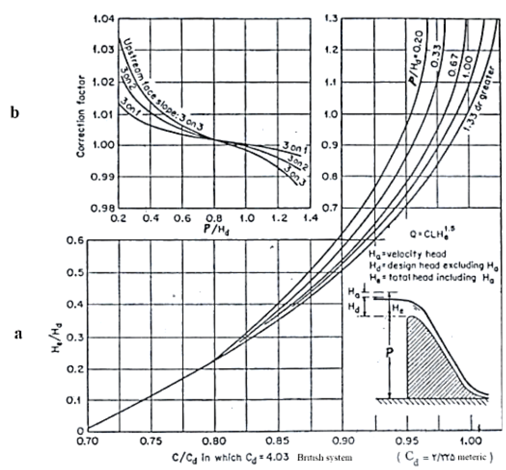


Figure 2: Flow coefficients in the WES spillway [12]

The genetic algorithm was used for optimization.

First, the target function and the constraints were coded. Then, this function was inserted in the MATLAB software command environment. The range of variables was written in the Bounds section of the genetic algorithm. Process of genetic algorithm is such that at first a number of initial solutions are implemented as the "primitive population" in the target function, then, according to Figure 3, the steps for implementing the algorithm are repeated until the desired solution is reached.

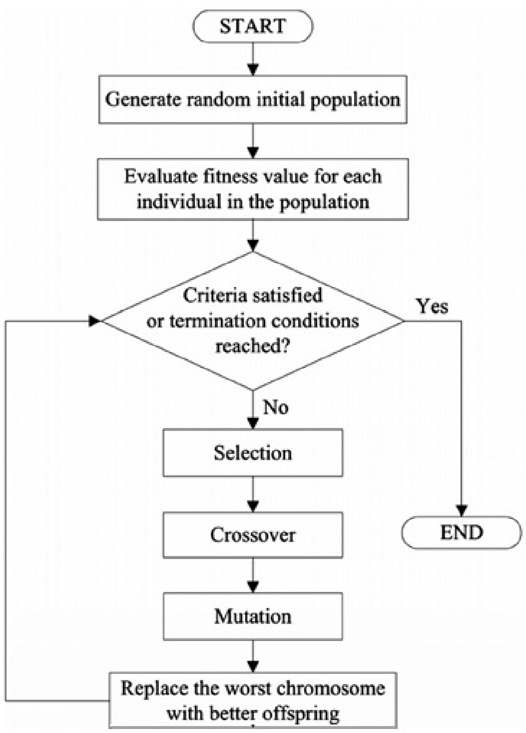


Figure 3: General procedure of genetic algorithm implementation [13]

In this method, first, for a fixed number called a population, a set of target parameters is generated randomly. After executing the program, the numerical simulator identifies the deviation of that set of information to that member of the population. This action was repeated for each member created. Then, by calling the operators of the genetic algorithm, including the opposition, mutation and selection operator, the next generation will be shaped and this procedure will continue to satisfy the convergence scale. Three parameters are commonly used as a stopping scale:

1. Duration of implementing the algorithm
2. Number of generation that are created
3. Convergence of the error criterion [14].

2.2. *Regression analysis*

In natural phenomena and experimental problems, there are several methods for estimating a parameter from one or more variables. One of the methods that predicts the behavior of a dependent variable is the multivariate linear regression model. This method is one of the simplest methods described for curve fitting [15]. A researcher can use linear regression if the following conditions are available [16].

1. Average (mathematical hope) errors should be zero.
2. The variance of the errors should be constant.
3. There should not be any correlations between the model errors.
4. The dependent variable should have a normal distribution.
5. Independent variables should not be linear.

In the linear regression model, the relation between independent variables $x(1), x(2), \ldots x(n)$ and the dependent variable Y is like:

$$Y = a(0) + a(1)x(1) + \cdots + a(n)x(n) + e \quad (4)$$

In equation (4) $a(0)$ is the y-intercept and $a(1), a(2)\ldots, a(n)$ are the regression coefficients and e is the error rate [17]. When N is in the variable and matrix mode, the linear multiple regression is like:

$$Y = X\beta + Z \quad (5)$$

In equation (5), Y is the vector of random variables and represents the expected data of the dependent variable. X is the matrix of independent variables, β is the matrix of regression coefficients, and Z is a random variable vector representing the error [18]. Significant tests are part of the inferential statistics that are based on the results of the sample on the population in which the sample is extracted. The assumption test is based on the studies of Sesser Ronald

Fischer (nineteenth and twentieth centuries), Jersey Nihsen (nineteenth century), and Karl Pearson (nineteenth and twentieth centuries). The modern assumption test is a combination of the work of these people, which was assigned to them in the twenty-first century [19]. In the discussion of statistical inference, that is, the analysis of the data and the generalization of its results to the statistical society, there is also a decision on the above-mentioned claims. In particular, the research hypotheses that are presented in the studies should be examined, validated or rejected by appropriate methods (statistical assumption tests). In this discussion, any hypothesis or question based on the difference or relation in analytical studies should be converted into statistical language (ie, statistical hypothesis) to be verified through statistical methods [20].

At first, various variables of (P/H) are extracted from the Figure 1 for the factor of discharge coefficient s 0,945; 0,953; 0,966; 0,975; 0,986. These variables lead to a specific relation to determine the volume of concrete used. The general objective is simplifying the calculation of the volume of concrete used in the design of ogee spillway. First, the factor of discharge coefficient (C/Cd) is converted to 5 discrete data from 0,945 to 0,9866 and thus the main problem of research (concrete volume minimization) is investigated in 5 phases. Figure 1. As already mentioned, being ideal was considered as the main constraint of spillway construction. The volume of concrete used in the spillway function was obtained from a special relation for the ideal flow of spillway profile. For 5 values of (C/Cd), the corresponding values of (P/H) were extracted from Figure 2, each of them has a specific relation for the volume of concrete used (Table 1).

The target functions were coded in MATLAB software, and each of the design components were defined in the programming language in the software. The Gatool was used to calculate minimum volume of concrete consumption. The parameters of the genetic algorithm were also optimized. The optimal parameters of the algorithm were obtained based on trial and error and the experiences derived from repeating the algorithm (Table 2). Version 7.14.0.739 was used for optimization.

Table 1: Extracted materials from Figure 2

C/Cd	P/Hd	Relation
0,945	0,2	$\frac{0,01\left(150P+1000P^2-37W\right)W}{w}$
0,953	0,33	$\frac{0,00165\left(90,9P+606,6P^2-37W\right)W}{w}$
0,966	0,67	$\frac{0,0033\left(44,77P+298,5P^2-37W\right)W}{w}$
0,975	1	$\frac{0,005\left(30P+200P^2-37W\right)W}{w}$
0,9866	1,33	$\frac{0,00665\left(22,55P+150,375P^2-37W\right)W}{w}$

Table 2: Optimized operators for genetic algorithm

Parameter	Type	Amount
Population	Population size	20
Population	Population Type	Double Vector
Fitness sclaing	Scaling Function	Rank
Selection	Selection Function	Stochastic Uniform
Reproduction	Elite count	2
Reproduction	Crossover Fraction	0,8
Mutation	Mutation Function	Constraint Dependent
Crossover	Crossover Function	Scattered
Migration	Fraction	0,2
Migration	Interval	20
Constraint Parameters	Initial Penalty	10
Stopping Criteria	Generation	100

2.3. *Definition of constraints (limitations)*

In the design of spillways, in addition to the hydraulic design, some of the main variables or relations between them should not be exceeded, for this purpose constraint design is used. This constraint determines boundary conditions related to different factors of the issue. The conditions of the issue are as follows:

$$0,945 < \frac{C}{Cd} < 0,986 \tag{6}$$

$$0,2 < \frac{W}{P} < 1,4 \tag{7}$$

$$\frac{y}{H} = 0,15 + 0,055\left(\frac{x}{H}\right) - 20,425\left(\frac{x}{H}\right)^2 \quad (8)$$

In the equation (6), (7) and (8), the final limit of x is equal to W and the final limit of y is equal to P and C/Cd is the factor of discharge coefficient, W is spillway of width (not length) and P is spillway height. First, for analyzing the genetic algorithm, the objective function was used in MATLAB software, and the operators of the genetic algorithm were measured by trial and error methods and the result was mentioned in Table 2.

3. Results and Discussions

In this study, the amount of factor of discharge coefficient (C/Cd) was reported in the amount (P/H) in Table 1. Equation (3) was also integrated and using the genetic algorithm, the minimum volume of concrete was performed. Then, relations were reported for the volume of concrete used in ogee spillway (Table 2). For correlation analysis and calculation of determination coefficient (R^2), RMSE value and error and reliability of two models, Excel 2010 and SPSS software were used. For different values of P/H, few models were designed. Regression models have been investigated separately in the following. The first model (P/H = 0,2) is the linear relation between the independent variable ($x = W/P$) and the volume of concrete of the spillway construction with the coefficient of determination ($R^2 = 1$) and ($RMSE = 1,05$) and ($p - value = 0,0$), ($SE = 0,0006$); which its numerical value is mentioned in Table 3 and its diagram is mentioned in Figure 4a. This equation is as follows:

$$y = 100,91x + 0,1771 \quad (9)$$

The second model ($P/H = 0,33$) is the linear relation between the independent variable ($x = W/P$) and the volume of concrete of the spillway construction with the coefficient of determination ($R^2 = 1$) and ($RMSE = 1,05$); which its numerical value is mentioned in Table 3 and its diagram is mentioned in Figure 4b. This equation is as follows:

$$y = 100,61x + 0,2926 \quad (10)$$

The third model ($P/H = 0,67$) is the linear relation between the independent variable ($x = W/P$) and the volume of concrete of the spillway construction with the coefficient of determination ($R^2 = 0,99$) and ($RMSE = 1,05$) and ($p - value = 0,0$), ($SE = 0,0079$); which its numerical value is mentioned in Table 3 and its diagram is mentioned in Figure 4c. This equation is as follows:

$$y = 98{,}743x - 0{,}2719 \quad (11)$$

The fourth model ($P/H = 1$) is the linear relation between the independent variable ($x = W/P$) and the volume of concrete of the spillway construction with the coefficient of determination ($R^2 = 0,99$) and ($RMSE = 1,05$) and ($p-value = 0,0$), ($SE = 0,001$); which its numerical value is mentioned in Table 3 and its diagram is mentioned in Figure 4d. This equation is as follows:

$$y = 98,742x - 0,2719 \quad (12)$$

The fifth model ($P/H = 1,33$) is the linear relation between the independent variable ($x = W/P$) and the volume of concrete of the spillway construction with the coefficient of determination ($R^2 = 0.99$) and ($RMSE = 1,05$) and ($p-value = 0,0$), ($SE = 0,0041$); which its numerical value is mentioned in Table 3 and its diagram is mentioned in Figure 4f. This equation is as follows:

$$y = 97,56x + 1,1794 \quad (13)$$

In the equations (9), (10), (11), (12) and (13), the component x represents the value of (W/P), and the component y is equal to the volume of concrete consumption per length in terms of (m^3/m).

3.1. Regression hypothesis test (t-Test)

The interpretation of a relation requires a hypothesis test. If the zero hypothesis was rejected, it can be concluded that there is a linear relation between two independent and dependent variables. In this study, t-test was used to interpret the regression model and SPSS16 software was used for calculations. The absence of linear relation of hypothesis:

$$H_0 : \beta_1 = 0$$

$$H_1 : \beta_1 \neq 0$$

The first model ($P/H = 0,2$): for the relation of length and height of spillway we have (Ln(P)) and $T-table$ with standard distribution and $p-value = 0,05$:

$$(t_0 = 1757,84; -3.44), \left(t_{\alpha/2\ n-2} = 2,57\right)$$

Consequently, we have $|t_{\alpha/2\ n-2}| < |t_0|$ and the assumption of H_0 is rejected and the linear relation of this model is confirmed. For simplicity and with the criterion error (S_{xy}) 1,153; we can use the following equation for this model:

$$Y = 100X \quad (14)$$

In equation (14), the component X represents the value of (W/P), and the component y is equal to the volume of concrete consumption per length in terms of (m^3/m).

The *second model* ($P/H = 0,33$): like other models, we have:

$$(t_0 = -3,44; 1062,90), \left(t_{\alpha/2\ n-2} = 2,57\right)$$

Consequently, we have $|t_{\alpha/2\ n-2}| < |t_0|$ and the assumption of H_0 is rejected and the linear relation of this model is confirmed. For simplicity and with the criterion error (S_{xy}) 0,984; we can use the $Y = 100X$ equation for this model.

The *third model* ($P/H = 0,67$): like other models, we have:

$$(t_0 = 0,446; 133,64), \left(t_{\alpha/2\ n-2} = 2,57\right)$$

Consequently, we have $|t_{\alpha/2\ n-2}| < |t_0|$ and the assumption of H_0 is rejected and the linear relation of this model is confirmed. For simplicity and with criterion error (S_{xy}) 1,802, we can use the $Y = 100X$ equation for this model.

The *forth model* ($P/H = 1$): like other models, we have:

$$(t_0 = 0,446; 133,69), \left(t_{\alpha/2\ n-2} = 2,57\right)$$

Table 3: Amount of concrete consumption per length

	Model				
W/P	1	2	3	4	5
0,2	20,285	20,293	19,947	19,947	20,2
0,4	40,54	40,537	37,797	37,797	40,2
0,6	60,766	60,733	59,549	59,549	60,013
0,8	80,963	80,88	79,204	79,2	79,62
1	101,13	100,978	98,761	98,761	99,038
1,2	121,267	121,027	118,22	118,22	118,25
1,4	141,374	141,027	137,582	137,58	137,27

1:$P/H = 0,2$; 2:$P/H = 0,33$; 3:$P/H = 0,67$; 4:$P/H = 1$; 5:$P/H = 1,33$;

Consequently, we have $|t_{\alpha/2\ n-2}| < |t_0|$ and the assumption of H_0 is rejected and the linear relation of this model is confirmed. For simplicity and with criterion error (S_{xy}) 1,803, we can use the $Y = 100X$ equation for this model.

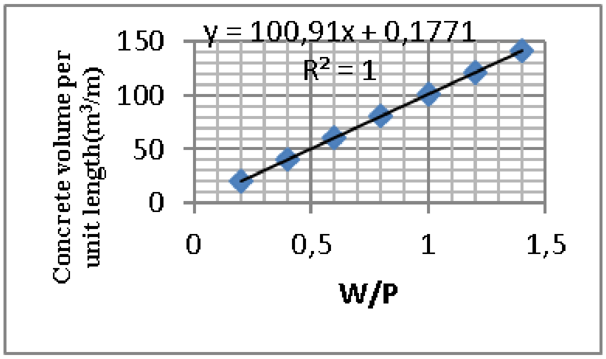
The *fifth model* ($P/H = 1,33$): like other models, we have:

$$(t_0 = -3,39; 255,45), \left(t_{\alpha/2\ n-2} = 2,57\right)$$

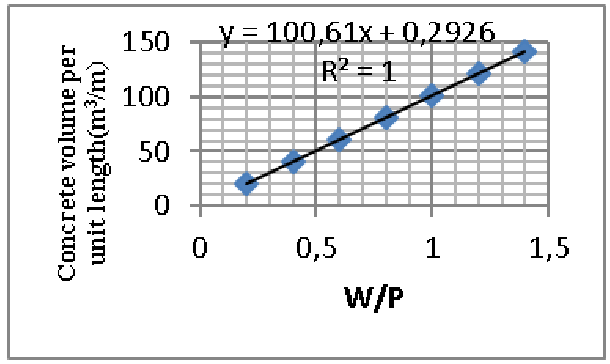
Consequently, we have $|t_{\alpha/2\ n-2}| < |t_0|$ and the assumption of H_0 is rejected and the linear relation of this model is confirmed. For simplicity and with criterion error (S_{xy}) 1,527, we can use the $Y = 100X$ equation for this model.

4. Conclusion

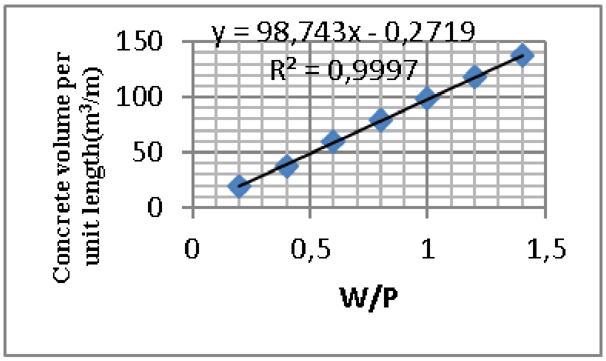
The first goal of the study is to minimize the volume of concrete used in the construction of ogee spillway. In this research we introduced the spillway height ratio (P/H) to design head of 5 models. Using genetics algorithms, the minimum volume of concrete consumption was calculated. The relations in Table 2 are based on the minimum volume of concrete and can be used in future designs of these models. In this study, the spillway was defined ideally and Equation (3) indicates the relation between the horizontal and vertical component (ogee spillway section). By integrating the enclosed area of the curve, the relation between the volume of concrete consumption and the geometric components (Spillway of height (P), width (W)) was determined. All calculations are



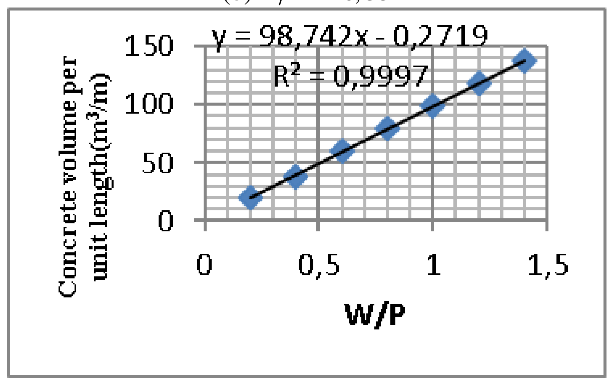
(a) $P/H = 0,2$



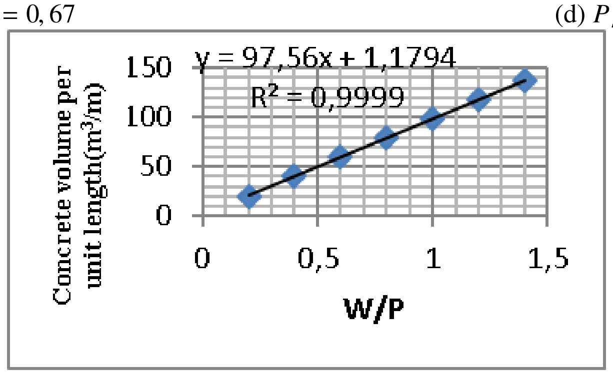
(b) $P/H = 0,33$



(c) $P/H = 0,67$



(d) $P/H = 1$



(e) $P/H = 1,33$

Figure 4: Changes in the amount of concrete volume consumption per length of ogee spillway

based on the ideal spillway characteristics. In this research, using correlation and regression, there is a linear and positive relation between the volume of concrete consumption in the ogee spillway and the geometric component (W/P). By choosing the optimal width (W) to spillway height, it saves significantly at the cost of concrete and operation. Also, the significance and accuracy of the regression model between concrete volume variable and geometric variable (W/P) indicate the high ability of models to estimate the relation between components. The study of the ogee spillway overflow and geometric characteristics of its structure is one of suggestions for researchers in the hydraulic and structural fields can have extensive studies on it.

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