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Optimizing geometric dimensions and vortex breaker of morning glory spillway using genetic algorithm: Case study of physical model of San Louis Forebay Dam in California, USA

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***Abstract*---**This research aims at optimizing geometric dimensions and vortex breaker of morning glory spillway using a genetic algorithm (a case study of a physical model of San Louis Forebay Dam in California, USA). In this research, two types of morning glory spillway, one with a smooth and the other with a stepped body, with different vortex breakers and different arrangements, are experimentally tested and modeled. In addition, a physical model, similar to the model of San Louis Forebay Dam located in California in the USA, was selected. This research optimized discharge coefficient and morning glory spillway height parameters using a genetic algorithm. The results show that tunnel radius parameters and inner and outer radii of the spillway crest, radius 90-degree bend, the length of the tunnel, and the height of the spillway crest can be optimized based on the total volume of the spillway using a genetic algorithm. In addition, the new values obtained for these parameters, if used, lead to a decrease equal to 39% of the volumes of concreting, which, in turn, reduces the building costs of the physical model.

***Keywords*---**morning glory spillway, spillway vortex breaker, geometric dimensions, San Louis Forebay Dam.

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Introduction

Optimization plays a key role in research, management, engineering, designing, and sciences. It deals with maximizing the output from many input variables that exert their relative influence on the output. For this purpose, a series of equations and inequalities are used vastly, which have a growing influence on engineering sciences. Afshar and colleagues (2007) investigated the optimization of the designing surface water collection network. Dehghan and colleagues (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 and others (2015) analyzed the sensitivity of the effective factors on aeration using fuzzy neural network and artificial neural network methods and obtained the significant amount of each parameter effective on aeration. Asghari and others (2008) estimated hydraulic parameters affecting the unconfined aquifer using a genetic algorithm.

Soltani and colleagues (2011) investigated effective factors on pipe failure rate in water distribution networks using a mix of the artificial neural network and genetic algorithm. Aslani and colleagues (2014) determined the values of the genetic algorithm parameters for optimization of the concrete gravity dams and obtained the best values for replication rate, the initial population, the mutation rate, and the selection rate. Fattor and others (2001) discussed upon the onset of submersion in the morning glory spillway and showed that this state is unstable and severe, and it leads to serious pressure fluctuations. Khatsuria (2005) conducted several research on pressure, submersion ratio, and discharge coefficient of the smooth spillways. The results of his research are in agreement with the results obtained by the US Department of Civil Engineering on smooth morning glory spillway. Novak and colleagues (2007) conducted a set of new studies on morning glory spillways and showed their results on submersion equations of spillway flow. Prof. B.S. Thandaveswara (2004) studied the stepped morning glory spillway model to obtain hydraulic parameters of the model in comparison with the main spillway and created some relationships between them. He also evaluated discharge effects by changing the height of the steps.Aghamajidi etal (2013) tried to study effect of vortex braker and steeped chmamber on morning glory spillway. He found out the vortex breaker has grate effect on Discharge coefficient and he also tried to formulate the effective empyting coeffiecieny of short throth shaft spillway. Other factors affecting vortex formation include insufficient submergence, current separation, and 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 are dependent 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 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 morning glory spillway. The results showed that the placement of 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 that are placed in narrow valleys and in 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 that of the design. 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, many articles have been published by genetic algorithms 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)]. Following this research, the present research aims at optimizing geometric dimensions and vortex breaker of morning glory spillway using a genetic algorithm (a case study of a physical model of San Louis Forebay Dam) in California, USA.

Materials and Methods

Physical model of morning glory spillway of San Louis Forebay Dam [8]

The purposes of this research-executive project are to provide the structural safety of dam and spillway and to design and implement morning glory spillways in a shorter time. Thus, two types of morning glory spillways, smooth and stepped and vortex breakers with different placements, were tested and modeled experimentally. In our research, we selected a physical model similar to the spillway model of the San Louis Forebay Dam in the Central Valley of California, USA. We also made a number of changes in the dimensions and scale of the model with a ratio of 1:50 to prepare it for experiments. This model, shown in figure 1, consists of several main parts, which are explained in the rest of this paper. The reservoir can be seen at the highest part of the model, which consists of a trapezoidal channel with the inlet of the spillway. This channel guides the water towards the spillway crest.

Dimensions are equal to $0.911\times 1.05\times 1.20$ (m3). The next part of the model is the body of the morning glory spillway, which can be separated from other parts. In this case, the stepped form of the spillway can be replaced with a simple form in each stage of the experiment (fig.2). The spillway length is more than 1.46 m, and the diameters of crest, throat, and bent are, respectively, equal to 35.00 cm, 7.00cm, and 10.6 cm. The diameter of the downstream tunnel to drain is equal to 7.62cm. The Downstream of the tunnel is equipped with a 2000-liter reservoir to store water. In the model, water is guided from downstream towards the trapezoidal channel in the dam reservoir by a 3-inch pump. When the upstream reservoir is full, water spills out from the crest spillway and enters into the downstream reservoir. This process is adequately repeated under the influence of the different discharges of the flow created by the pump.

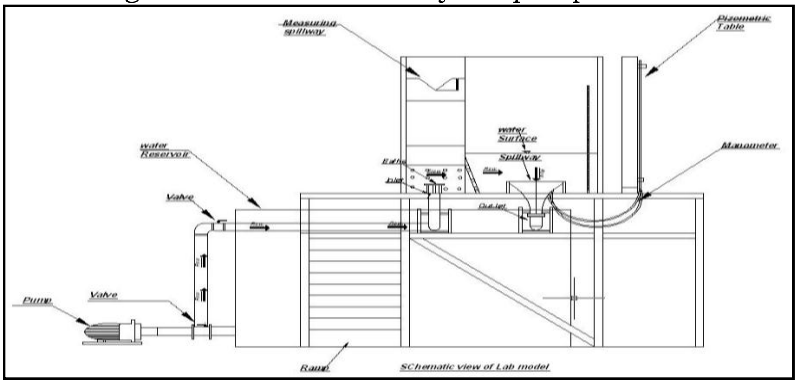

Figure 1. Cross-section of the physical model of the dam and spillway

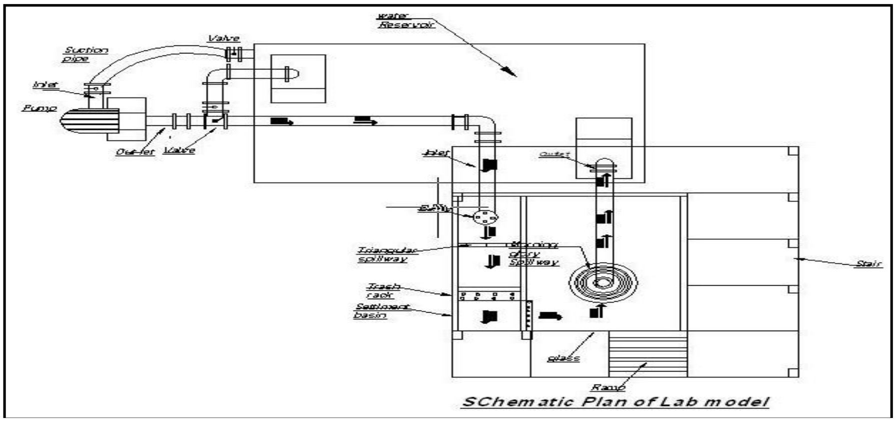

Figure 2. A view of the stages of constructing the physical model of the reservoir and the location of the spillway

3-way valves were used to control discharges in this way that in the flow path immediately after the pump, the flow returns to the reservoir, and the other part is immediately transferred into the reservoir by a 90-degree elbow. The aim of this operation was to entirely control the inlet flow rate into the reservoir by two inlet valves, one towards the spillway reservoir and the other towards the impoundment reservoir (2000-liter reservoir). Once the water enters the dam reservoir by a triangular spillway, the inlet to the spillway site is measured. Then after passing a stilling part, it moves towards the morning glory spillway.

Different parts of the physical-hydraulic model

Impoundment reservoir: to transfer water into the spillway reservoir. In this research, an impoundment reservoir with a volume equal to 2000 liters was used (dimensions: $1.1 \times 1.1 \times 2.1$) made of a 3 mm steel sheet. Spillway reservoir (the location of the spillway, dimensions: $1.20 \times 1.1 \times 1.2$): It was made of a 4 mm steel sheet (completely confined) and 10 mm glass sheet so that inside the reservoir can be observed. This reservoir is completely balanced. The reservoir was equipped with braces to prevent any movement due to the flow and impact. For more protection, a rolling bolt was used to connect the reservoir to the pump to the ground. The inside of the reservoir is made up of different parts.

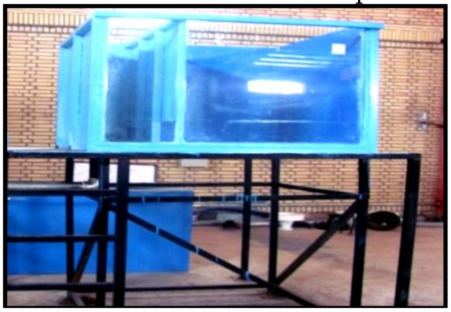

Figure 3. A view of spillway reservoir in the physical model

Water inlet from the impoundment reservoir: A 90-degree 3-inch pipe is used to connect the impoundment reservoir to the spillway reservoir. The water enters immediately into the reservoir. Damper (Baffle): to reduce the strength and intensity of flow fluctuations in the reservoir, the damper system is used immediately after the water enters the reservoir.

Triangular spillway

To measure the discharge entered into the dam reservoir, a triangular spillway with dimensions of 0.2m × 0.2m × 0.2m (with an internal angle of 60 degrees) was used. This spillway was calibrated with different discharges. (Figure 4)

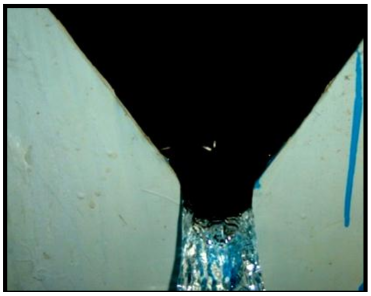

Figure 4. A view of the triangular spillway

Second damper: This part is a chamber that is connected to a spillway reservoir by two trash rocks.Different stages of fluid movement in the model: first, water is pumped into the impoundment reservoir. Then, it enters into the spillway reservoir, passes through the damper, and enters into the spillway. A 90-degree 3-inch flange-welded elbow is connected to the outlet pipe of the reservoir and finally to the impoundment reservoir. A geometric panel is used in different parts of the morning glory spillway to control the pressure. This panel is equipped with scales and 4 mm thin, transparent pipes, which are connected to different parts of the spillway, and different water heights can be investigated and read based on location in the dam. Vortex breaker (vortex breaker curtain): We needed to use different types of vortex breakers for performing different stages of the experiments. To make vortex breakers, compressed plastic (thick Teflon) with different types of a thickness (thickness 19.5mm, 14mm, and 210mm) is used. These vortex breakers are designed and prepared in different dimensions and sizes, and they are connected to the body of the spillway using a 6 mm automatic screw; and their arrangement is in the form of 3, 4, 6 pieces.

Figure 5. A view of the location of the spillway reservoir

For this physical model (Figs. 6-10), five different crossing sections or spillway openings are designed according to Figure 11-13. The same design is used for all five types of the spillway. The radius of the inlet curvature or small circle of the spillway is 6.10 cm, and the radius of the big curvature of each spillway is 3.20 cm. The height of each spillway is 28.20 cm. The roughness of the wall of each spillway is different from the other. This difference can be seen in the spillways as well. In spillway type 1, the wall is entirely smooth and curved. In the other four types, the walls are curved but stepped. In spillway type 2, the width of each step is 1 cm, and the height of the steps is different. Thus, the spillways are named based on the number of their steps. For example, spillway type 2 is named 11-stepped spillway. The spillways types 3 to 5 are, respectively, called 6, 4, and 3 stepped spillways. As we said earlier, each step has a different height from others, but the widths of all steps in each spillway are equal. Thus, the widths of each step in spillways type 3 to 5 are considered 2, 3, and 4 cm, respectively. 1, 2, 3, and 4 holes are embedded in spillways type 2 to 5, on the horizontal surface of each step, in spillways type 2 to 5, respectively, in order to measure psychometric pressure. The embedded holes in the smooth spillway are exactly similar to the holes in spillway type 2. Five types of the spillway model are made of compact Teflon with lathing capability, and they are cut with an advanced lathe machine, known as CNC, as shown in the figure below:

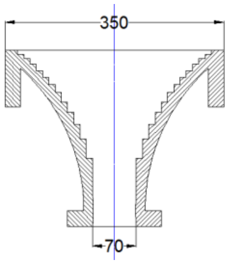

Figure 6. A physical model of the simple spillway

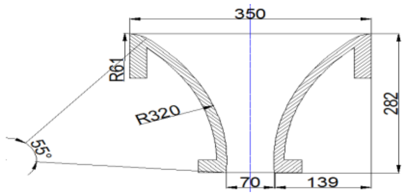

Figure 7. a physical model of 11 step spillway

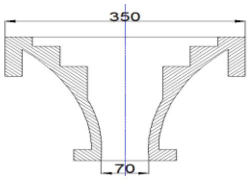

Figure 8. a physical model of 6 step spillway

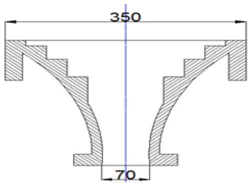

Figure 9. a physical model of 4 step spillway

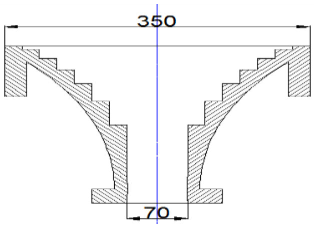

Figure 10. a physical model of 3 step spillway


Figure 11. (right to left) simple spillway and 12-step spillway

Figure 12. (right to left) 6-step spillway and 4-step spillway

Figure 13. 3-step spillway

In table 1, general characteristics of the physical model have been presented

Table 1
General characteristics of the physical model of dam and spillway

Model characteristics	Length (cm)	Width (cm)	Height (cm)	Radius(cm)	Area (cm^2)	Volume(lit)	slope
Physical model	370.00	105.00	225.00	---	---	---	0.00
Dam reservoir	120.00	105.00	91/10	---	---	1000	0.00
Right slope of reservoir	11.10	26.20	27.75	---	---	---	0.40
Five models of the spillway	---	---	28.20	17.50	962.11	---	0.00
90-degree bent	---	---	---	5.08	81.07	---	0.00
Dam water transfer tunnel	214.09	---	---	7.62	45.60	---	0
Downstream reservoir	2.00	1.00	1.00	---	---	2000	0.00
Pentax pump	---	---	1200	---	---	9.12	0.00

Dimensional analysis

In this research, Buckingham π theorem was used for dimensional analysis. A relation as follows was created using variables involved in the problem:

$$\mathbf{f(cd, H, Ds, n, v, g, \rho, \upsilon, \delta, k, f, Q, a) = 0} \quad (1)$$

Where:
Cd: coefficient of the morning glory spillway
H_0: height water over the spillway
D_s: diameter of the morning glory spillway
n: number of the vortex breaker
a: height of the vortex breaker
v: water velocity over the spillway
g: gravity acceleration
p: fluid density (water)
υ: kinematic viscosity
Q: discharge of the morning glory spillway
S: surface tension
e: width of the steps
h: height of the steps
I: height of the spillway

The parameters can be examined using the following equation:
(2)

$$f(Cd\,, {}^{\mathrm{H_0}}\!/_{\mathrm{Ds}}, \frac{h}{Ds}, fr, n, a, \mathrm{Re}, We, e) = 0$$

In this research, parameters such as the type of vortex breaker, including (number, type, and length) discharge, the height of water and type of step, and its effect on the discharge coefficient of the morning glory spillway were examined to simplify and reduce the number of tests and parameters under study.
Other parameters were excluded due to their low effect and to reduce experiments.

(3)

$$Cd = f({}^{H}\!/_{D}, fr, n, {}^{f}\!/_{H}, {}^{a}\!/_{H}, e) = 0$$

For the flow over the spillway crest without the submersion, the above relation is used for dimensional analysis. In the case of submersion, the following relations are created:

(4) $\mathbf{f(H_{sa}, \rho, D_s, h, l, g, v_{sa}) =}$

(5) $\mathbf{\Pi_1 = (v_{sa}, \rho, D_s, H_{sa}) = \frac{H_{sa}}{D_s}}$

(6) $\mathbf{\Pi_2 = (v, \rho, D_s, h) = \frac{h}{D_s}}$

(7) $\mathbf{\Pi_3 = (v, \rho, D_s, l) = \frac{l}{D_s}}$

Froude number of submersion flow (8) $\Pi_4 = (v, \rho, D_s, g) = \frac{gD_s}{v_{sa}^2} = Fr_{sa}$

Thus, relation without the above dimensions is:

(9) $$F\left(\frac{H_{sa}}{D_s},\frac{h}{D_s},\frac{l}{D_s},\frac{gD_s}{v_{sa}^2}\right)=0\rightarrow\frac{gD_s}{v_{sa}^2}=F\left(\frac{H_{sa}}{D_s},\frac{h}{D_s},\frac{l}{D_s}\right)$$

If the flow is over the curved wall of a smooth spillway and stepped wall of the stepped spillway, the dimensionless relations are:

$$f\left(y,\rho,D_s,h,l,g,v_i,\frac{\Delta p}{L},\mu,\alpha\right)=0 \quad (10)$$

(11) $$\Pi_1=(v_i,\rho,D_s,H_0)=\frac{y}{D_s}$$

(12) $$\Pi_2=(v_i,\rho,D_s,h)=\frac{h}{D_s}$$

(13) $$\Pi_3=(v_i,\rho,D_s,l)=\frac{l}{D_s}$$

(14) Froude number of walls $\Pi_4=(v_i,\rho,D_s,g)=\frac{gD_s}{v_i^2}=Fr_i$

Reynolds number wall (15) $\Pi_5=(v_i,\rho,D_s,\mu)=\frac{\mu}{\rho v_i D_s}=Re_i$

Euler number wall (16) $\boldsymbol{\Pi_6=\frac{\frac{\Delta p}{L}D_s}{0.5\rho v_i^2}=\frac{\Delta p}{0.5\rho v_i^2}=\mathbf{Euler}}$

(17) $\boldsymbol{\Pi_7=\alpha}$

And the equation for the dimensionless relations above is:

(18) $$\mathbf{F}\left(\frac{y}{D_s},\frac{h}{D_s},\frac{l}{D_s},\frac{gD_s}{v_i^2},\frac{\mu}{\rho v_i D_s},\frac{\Delta p}{0.5\rho v_i^2},\boldsymbol{\alpha}\right)=\mathbf{0}\rightarrow\frac{\Delta p}{0.5\rho v_i^2}=\boldsymbol{\sigma_c}=\mathbf{F}\left(\frac{y}{D_s},\frac{h}{D_s},\frac{l}{D_s},\frac{gD_s}{v_i^2},\frac{\mu}{\rho v_i D_s},\boldsymbol{\alpha}\right)$$

Measurement of the basic parameters

The height of water over the spillway (h_0) and the height of the water surface is measured using a metal staff gage (1m). Glass cylinder dimensions are 0.55m×0.55m×10m. Discharge of the outlet water over the spillway is measured by volume after being read. This operation is repeated for different discharges.It is assumed that the pressure at the reservoir water level and near the water inlet of the spillway is zero. This assumption is not true for spillways with smooth and stepped walls, but it is considered for all discharges. Then the piezometric tubes installed in different points of the height of the triangular spillway are transferred to the piezometers, and then the pressure and height of the water are read on their different points.During this research, the parameters of geometric dimensions and vortex breaker of the morning glory spillway were investigated using a genetic algorithm.

Findings
Optimizing geometric dimensions of the spillway

in the rest of the paper, optimization of the geometric dimensions of the morning glory spillway is addressed, and at the final, the optimal dimensions to reduce the volume of concreting and, as a result, the cost is presented. The objective function defined in MATLAB

```
z=(pi*(Rs+r+T).*(sqrt((Ht).^2).*(Rs-r+T).^2))+(pi.*Lt.*((Rt+T).*2))+(pi.*((Rv+T).^2));
```

The results are presented in the rest of the paper: the horizontal axis represents the volume, and the vertical axis represents the given parameter.

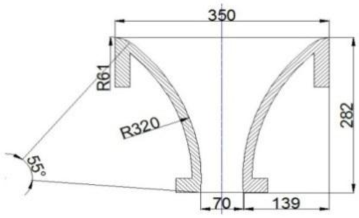

Figure 14. A view of the morning glory spillway and its dimensions

Radius 90-degree bend: in this model, it is equal to 5.08, which the genetic algorithm proposes for values between .025 to .098 for a radius 90-degree bend in a Pareto front according to the volume between .2 to .8. Considering the method of selection (.7919), .0251 is considered as the optimal volume value.

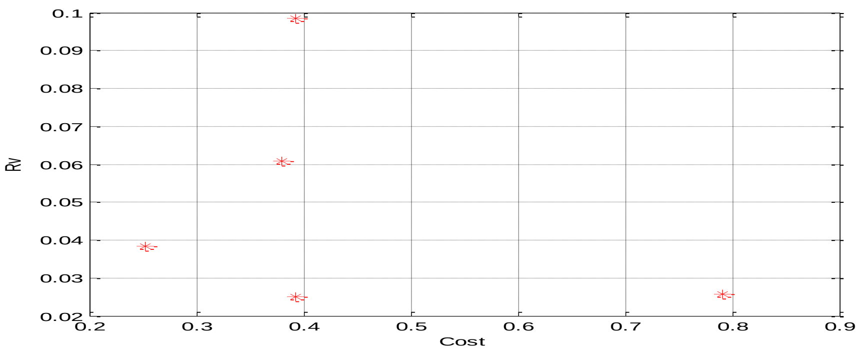

Figure 15. Radius 90-degree bend- optimized volume by genetic algorithm

Table 2
Values obtained for Radius 90-degree bend in Pareto Front by genetic algorithm

Data Statistics - 1

Statistics for data1

Check to plot statistics on figure:

	X	Y
min	0.2518	0.02511
max	0.7919	0.09857
mean	0.4416	0.04974
median	0.392	0.03844
mode	0.2518	0.02511
std	0.2046	0.03091
range	0.5401	0.07347

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The outer radius in the physical model is equal to 175. By selection of the optimal concreting volume equal to .7917 m³, the value of .249 is considered for the outer radius. The diagram related to the Pareto front is shown in figure 16.

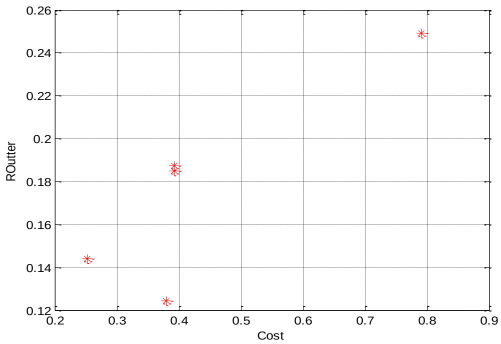

Figure 16. Outer radius - optimized volume by genetic algorithm

Table 3
optimized values obtained for the outer radius in Pareto Front by genetic algorithm

Data Statistics - 2

Statistics for data1

Check to plot statistics on figure:

	X	Y
min	0.2518	0.1243
max	0.7919	0.2493
mean	0.4416	0.1779
median	0.392	0.1847
mode	0.2518	0.1243
std	0.2046	0.04811
range	0.5401	0.125

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The tunnel radius in the physical model is equal to .0762. This value is considered to be.1345 regarding the optimal value of concreting by the genetic algorithm equal to .7919. The diagram formed in the Pareto front and its table of values are as follows:

Table 4
optimized values obtained for tunnel radius in Pareto Front by genetic algorithm

Data Statistics - 3

Statistics for data1

Check to plot statistics on figure:

	X	Y
min	0.2518	0.04128
max	0.7919	0.1345
mean	0.4416	0.06942
median	0.392	0.04793
mode	0.2518	0.04128
std	0.2046	0.03995
range	0.5401	0.09324

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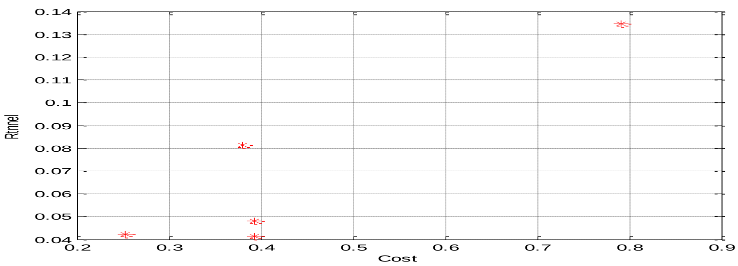

Figure 17. The diagram of tunnel radius- the optimized volume of morning glory spillway

Table 5
Optimized values obtained for spillway crest in Pareto Front by genetic algorithm

Data Statistics - 4

Statistics for data1

Check to plot statistics on figure:

	X	Y
min	0.2518	0.2002
max	0.7919	0.33
mean	0.4416	0.227
median	0.392	0.2005
mode	0.2518	0.2002
std	0.2046	0.05764
range	0.5401	0.1299

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The height of the spillway crest in the current state is equal to 28.2, which according to the optimal value of concrete is equal to .7919, its value in the Pareto front is equal to 22.7. The diagrams related to the Pareto front and the table related to it are shown in figure 18.

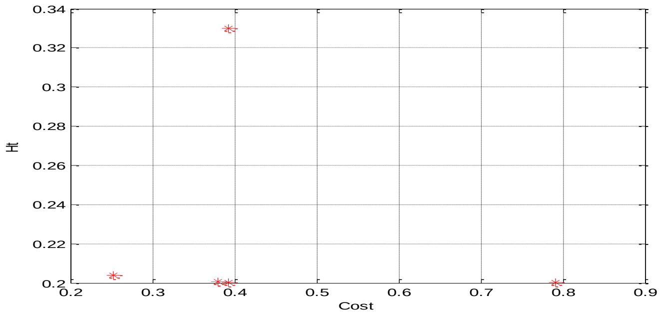

Figure 18. height of the spillway crest- optimized volume

The length of the tunnel is currently equal to 214.09, which according to .7919 for the optimal volume of concrete, the length of the tunnel is considered equal to 219.

Table 6
Optimized values obtained for the length of the tunnel in Pareto Front by genetic algorithm

Data Statistics - 5

Statistics for data1

Check to plot statistics on figure:

	X	Y
min	0.2518	1.561
max	0.7919	2.48
mean	0.4416	1.976
median	0.392	2.082
mode	0.2518	1.561
std	0.2046	0.4051
range	0.5401	0.9184

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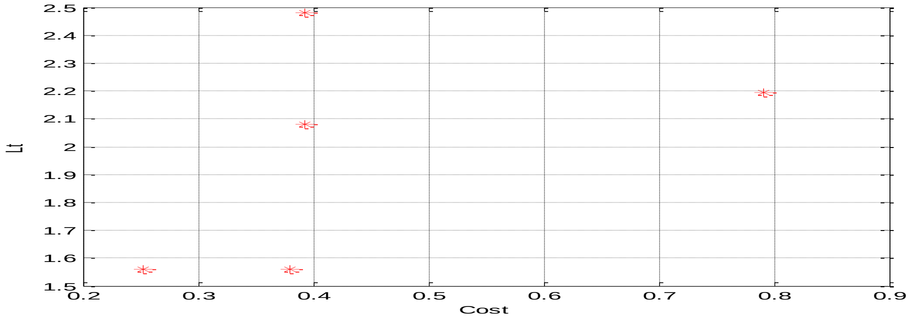

Diagram 19. Length of the tunnel- the optimized volume of the morning glory spillway

The current inner radius of the spillway is considered to be 3.5, which is considered to be 2.5 according to the selection of concreting volume equal to .7919. The diagram and table related to the Pareto front information are shown below.

Table 7
Optimized values obtained for inner radius of the spillway in Pareto Front by genetic algorithm

Data Statistics - 6

Statistics for data1

Check to plot statistics on figure:

	X	Y
min	0.2518	0.02534
max	0.7919	0.08317
mean	0.4416	0.05413
median	0.392	0.06401
mode	0.2518	0.02534
std	0.2046	0.02554
range	0.5401	0.05782

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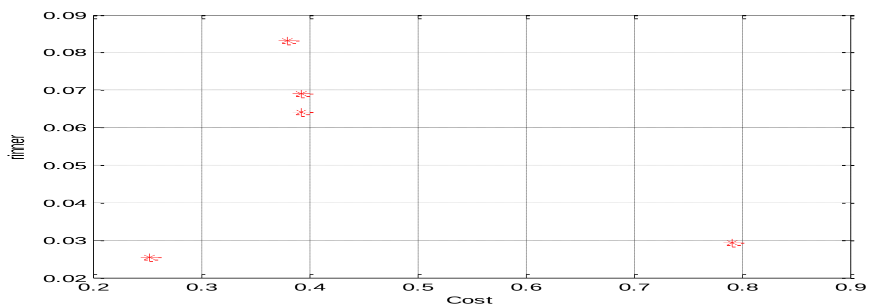

Diagram 20. Tunnel radius: optimized volume by genetic algorithm

Table 8
Table of optimized dimensions of morning glory spillway by genetic algorithm

	Current value	Value suggested by the algorithm	Percentage of decrease and increase
radius 90-degree bend	5.08	2.51	-50.5%
Tunnel length	214.09	219	+2.29%
outer radius	17.5	17.79	1.67%
inner radius	3.5	2.5	-28.57%
Tunnel radius	7.62	13.54	+77.69%
Height of the crest	28.2	22.7	-19.5%
volume	1.31	.7919	-39.54

Conclusion

This research aims at optimizing geometric dimensions and vortex breaker of morning glory spillway using a genetic algorithm (a case study of a physical model of San Louis Forebay Dam) in California, USA. Tunnel radius parameters and inner and outer radii of the spillway crest, radius 90-degree bend, the length of the tunnel, and the height of the spillway crest can be optimized based on the total volume of the spillway using a genetic algorithm. In addition, the new values obtained for these parameters, if used, lead to a decrease equal to 39% of the volumes of concreting, which, in turn, reduces the building costs of the physical model.

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