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Experimental Study of Effect of Guide Vanes on the Discharge Coefficient of Triangular Labyrinth Spillway

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Abstract: The labyrinth spillways are utilized to cater a more discharge capacity than straight overflow spillways. The capacity of a labyrinth spillway has dependents on total head, effective crest length, and discharge coefficient. The labyrinth spillway is utilizing as an overflow structure in large reservoirs. In the present study, guide vanes were utilized to increment the discharge coefficient of triangular labyrinth spillway. The different configurations of guide vanes on the upstream face of the spillway in a rectangular horizontal channel were examined. These different configurations were repeated for 3 widths of guide vanes. Experiments were operated for sub-critical, stable and free overflow conditions. Finally, the results show that the discharge coefficient of the triangular labyrinth spillway putting guide vanes had higher values than that of simple triangular labyrinth spillway. Putting 4 guide vanes in the first-quarter and fourth-quarter of two side legs can increment the discharge coefficient up to 18 %.

Keywords: Triangular labyrinth spillway; Guide vane; Discharge coefficient.

Introduction

Spillways are usually utilized for outflow measurement, control of flood in reservoir, and control of water level in irrigation systems. Labyrinth spillways are bended in the plan view to cater a higher discharge capacity than do straight overflow spillways (Fig. 1). For large reservoirs, the labyrinth spillway can be utilized as an overflow structure. It allows the overflow sill to be enhanced for the same maximum level of water and flood, and then, increment the storage capacity of the reservoir [1]. The equation below can be used to calculate of the labyrinth spillway discharge:

$$Q = \frac{2}{3} C_d \sqrt{2g} L H_t^{3/2} \quad (1)$$

Where in, C_d = the discharge coefficient; L = the effective length of labyrinth spillway; H_t = the total head over the spillway crest; g = the acceleration of gravity; and Q = the flow discharge. The coefficient C_d has relevance to the flow characteristics and geometry of the channel and spillway [2]. Labyrinth spillways with various cross sections, such as trapezoidal, rectangular, and triangular, have been utilized in practice. The spillways of this type may be of one bend or multiple bends and may be sharp-crested or broad-crested [1]. Labyrinth spillways have been utilized for decades [3]. Wide research about behavior of labyrinth spillways has been investigated by Taylor [4]. Taylor provided results in terms of magnification ratio, i.e., ratio of discharge over labyrinth spillway and normal spillway for the same head over the crest. Hay and Taylor [5, 6] developed design specifications of labyrinth spillways. Tullis et al. [7] expressed that the discharge coefficient of labyrinth spillway depends on total head, spillway height, spillway wall thickness, crest shape, and apex angle. Utilizing the piezo-metric head did not allow for differences in the approach velocity and could express significant errors in prediction [7].

The total head instead of the piezo-metric head is utilized in Houston [8, 9] and Lux [10] investigations. Soft computing techniques for the hydraulics of spillways utilized by Emiroglu et al. [11] and Bilhan et al. [12]. It was explained that for the same value of water head, the triangular spillway would discharge more than would the normal spillway [11, 12]. Ferro [13] operated the dimensional analysis and incomplete self-similarity theory for a sharp-crested and broad spillway. It theoretically deduced stage discharge and tested it using measurements obtained in the laboratory and from literature.

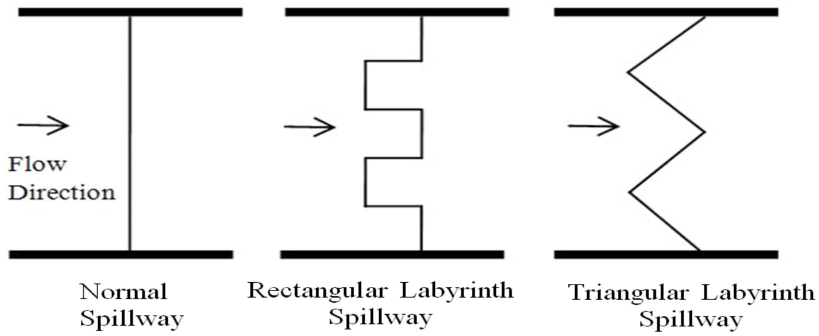

Fig1. *Labyrinth spillway planforms*

A theoretical approach utilized by Parvaneh et al. [14] for the hydraulics of triangular planform spillways under free flow condition in a rectangular flume. It was expressed that for low depths of flow passing over the spillway, streamlines were relatively perpendicular to the labyrinth spillway crest. Therefore, the whole length of the spillway crest was utilized. However, as the flow depth incremented, the orthogonality of streamlines with spillway crest gradually reduced. Therefore, the consequence of crest length can be reduced by utilizing the labyrinth geometry. In the labyrinth spillway, with an increment of flow amount from Q_1 to Q_3 and a consequent increment of total head from H_1 to H_3, the orthogonality of streamlines with spillway crest reduces significantly and thus, the effective length of spillway crest reduced from $l_1^{'}$ to $l_3^{'}$, it causes a significant reduce in the discharge coefficient from C_{d1} to C_{d3} (Eq. 2) [14]:

$$Q_1 < Q_2 < Q_3 \Rightarrow H_1 < H_2 < H_3 \Rightarrow l_1^{'} > l_2^{'} > l_3^{'} \Rightarrow C_{d1} > C_{d2} > C_{d3} \quad (2)$$

Kabiri-Samani et al. [15] utilize vanes or piles for investigation of the hydraulic efficiency of labyrinth side spillways. They explained that utilizing guide vanes significantly increased the discharge coefficient of labyrinth side spillway.

Over a triangular labyrinth spillway, streamlines tend to deflect when they are passing over the spillway but not when perpendicular to the spillway plate. Therefore, employing guide vanes with different arrangements in the flow field could have effected on the flow direction and thus, would be suitable for making better the hydraulic performance of the spillway (Fig. 2).

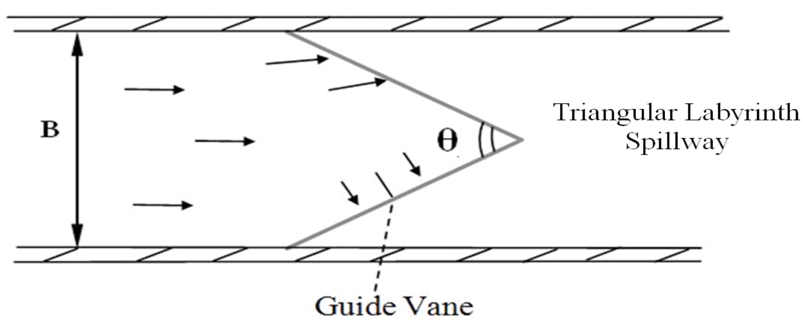

Fig2. *A schematic of guide vane location at the upstream face of the triangular labyrinth spillway*

In the present study, to increment the discharge coefficient of the sharp-crested triangular labyrinth spillway more, utilizing the guide vanes on the upstream face of the spillway is taken into consideration. The consequence of guide vane configurations on the discharge coefficient of the spillway was experimentally examined. Experiments were operated in a rectangular horizontal channel.

Theory

The discharge coefficient of labyrinth spillway depends on many parameters relevant to the spillway geometric and flow characteristics. Referring to Fig. 3, an operational relationship linking the flow over the guide vane triangular labyrinth spillway is expressed as:

$$\varphi(Q, H, P, L, L_V, N, S, g, \sigma, \mu, \rho) = 0 \qquad (3)$$

Where in, Q = the flow discharge; H = the total head over the spillway crest; P = the spillway height; L = the crest length of the triangular labyrinth spillway; L_v = the width of the vane; N = the number of the vanes; S = the situation of vanes; g = the acceleration of gravity; σ = the surface tension of fluid; μ = the dynamic viscosity of the fluid; and ρ = the density of fluid.

With consider of H, Q, and ρ as dimensional independent variables and with use the dimensional analysis, C_d is expressed in the following form:

$$C_{dv} = \phi\left(\frac{H}{P}, \frac{L}{P}, \frac{L_V}{L}, N, S, W, R\right) \qquad (4)$$

Where in, R and W is the Reynolds number and Weber number, respectively. Henderson [16], Novak and Cabelka [17] showed that the result of the Reynolds number and the Weber number could be insignificant except for very low values of the measured total head over the spillway. For all of tests examined in the present study, L and P were the same. Therefore, the effect of L/P on discharge coefficient was neglected. If the consequences of Reynolds number and Weber number can also be ignored, the discharge coefficient equation of guide vane triangular labyrinth spillway is:

$$C_{dv} = F\left(\frac{H}{P}, \frac{L_V}{L}, N, S\right) \qquad (5)$$

According to a specific classification, flow in the channel can be free and submerged. In free overflow, the downstream water level is less than the spillway height. If the downstream water level was higher than the spillway height, flow will be submerged. In this study, all tests were performed in free overflow conditions. In stable flow, the flow parameters, includes the flow depth, do not change in a constant cross section of the flow in length of time. In this study, the flow discharge was adjusted by flow valve adjustment. After a few minutes, the flow with a certain discharge was continuously established in the channel. Measurements of upstream water depth and flow velocity were performed. These conditions were observed for both normal spillway and triangular Labyrinth spillway measurements.

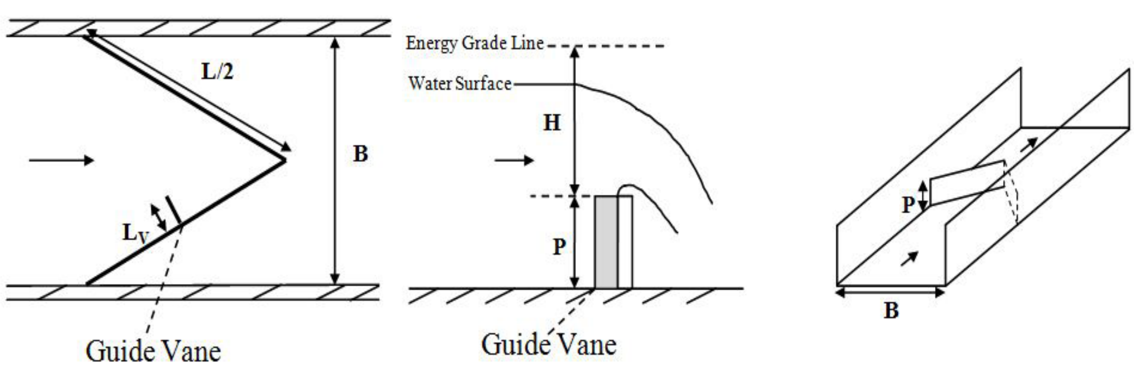

Fig3. *General flow characteristics over the guide vane triangular labyrinth spillway*

The water flow in the channels has a free surface. The force of gravity is the motive force in the channels. The force of gravity in the form of the dimensionless parameter as the Froude number (Fr) is expressed. In the physical modeling of flow with free surface, the dynamic similarity between the model and the original sample is generally based on the Froude number (Fr). In subcritical flow, Froude number (Fr) is less than one. That in this case, for a constant flow, the flow depth is high and the mean flow velocity is low. In this study, in all experiments, the Froude number (Fr) was calculated from equation 1 and all data were obtained in subcritical flow. Computing of Froude number (Fr) for rectangular channel is as follows:

$$Fr = \frac{V}{\sqrt{g/Y}} \quad (6)$$

Where in, V is mean flow velocity (m/s), Y is flow depth(m) and g is acceleration of gravity (m/s^2)

Sub-critical, stable and free overflow conditions were prepared for doing all experiments.

Experimental Setup and Method

Experiments were operated in a smooth rectangular horizontal Plexiglas flume 7.5 m long, 0.32 m wide, and 0.36 m high. Using grid walls and wave suppressors at the upstream of the flume could be effective on breaking large size eddies and dissipating surface disturbances, respectively. Triangular labyrinth spillway models were produced of galvanized steel plates with sharp edges. Parvaneh et al. (2010) expressed that the highest decrease in hydraulic efficiency of weir was occurred in the lowest of apex angle, θ = 45°[18]. Therefore, in this study, the apex angle (θ) = 45° was used. The spillway installed with distance of 4.5 m downstream of the head of the channel. An Acoustic Doppler Velocity (ADV) is employed to measuring the velocity of flow. Velocity profiles on 1.0 m and 2.0 m upstream of the spillway crest were provided to make sure that the approach flow was fully developed. Results explain that for each test the measured velocity profiles were nearly fitted together and the approach flow was fully developed. Flow discharge was measured using an electromagnetic flow meter with an accuracy of ±0.5%. Measuring of the approach flow depth was 1.0 m upstream of the spillway crest by using a point gauge of accuracy ±1 mm. For omitting the consequence of Reynolds number and Weber number on the discharge coefficient, the minimum nappe height over the spillway was taken more than 30 mm.

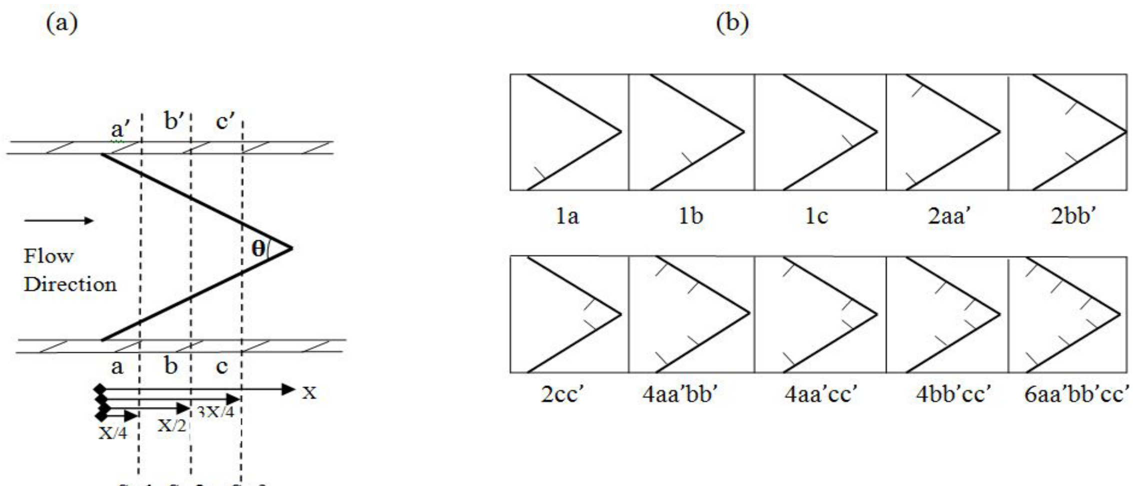

Fig4. *Planform of guide vane triangular labyrinth spillway models; a) Situation of guide vanes; b) arrangement and nomination of guide vane groups*

For each spillway model, 5 discharges (between 15 and 19 lps) were examined. Fig. 4 displays all of arrangements, positions, and configurations of guide vane groups on the upstream face of triangular labyrinth spillway in the present study. It is noteworthy that 1, 2, …, and 6 are the number of vanes, and *a, b, c, a′, b′* and *c′* display the position of vanes. For example, In Fig. 5, model (6aa'bb'cc') with vane width =1 cm located in the channel is shown. These conditions were repeated for 3 guide vanes with 1, 2 and 3 cm widths. The widths of guide vanes were equal to 1.25, 2.50 and 3.75% of the crest length of the triangular labyrinth spillway (Fig. 6). Cause of using three vane widths, is investigating the effect of the width of the guide vanes on the spillway hydraulic performance. It is important to note that width of guide vanes shall be limited to the condition of no back-water incidence in the approach flow.

According to the suggested relation, $\frac{W}{P} \geq 2.5$, by Hay and Taylor (1970), the height of spillway models was considered 12 cm. (Where in, W is the spillway width and P is the Spillway height).

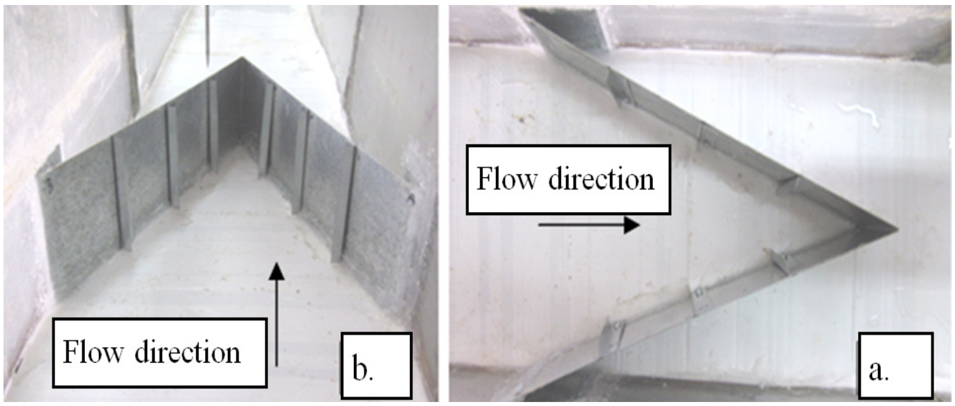

Fig5. Model (6aa'bb'cc') with vane width =1 cm located in the channel, a. Plan, b. View from the front

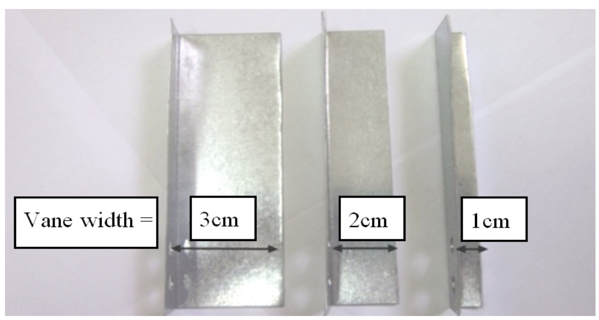

Fig6. Guide vanes with 3 width (1, 2 and 3 cm)

Results

For each test, the discharge coefficient computes from Eq. (1) and uses direct discharge measurement data. Then results are displayed against *H/P* in Fig. 7 for three different ratios of L_v/L. Also, the discharge coefficient data of simple triangular labyrinth spillway is drawn for comparison. It is understandable from Fig. 7, for most arrangements of guide vanes the discharge coefficient of guide vane triangular labyrinth spillway was larger than the discharge coefficient of simple labyrinth spillway. In L_v/L=1.25% (vane width=1cm), the discharge coefficient was more than the discharge coefficient in other ratios. According to diagrams of Fig.7, it was found that the use of one vane of each of the three widths has positive effect on increasing the discharge coefficient. About vane with 1cm width, all of models had a positive effect on increasing the discharge coefficient. About vane with 2cm width, it was shown that the position of vane/vanes on the axis b-b' (refer to Fig. 4) had a positive effect on increasing the discharge coefficient. But by increasing the width of the vane to 3cm, increasing in the number of vanes has a negative effect on the weir performance. It can be said that the utilization of vane with maximum 2cm width for this weir can be effective.

Increasing the length and number of vanes was cause of increment the water head over the spillway crest. Therefore, decrement in the discharge coefficient was happened.

In Fig. 8, the discharge coefficient of simple triangular labyrinth spillway from the present study was compared with the results of Tullis, et al. [7]. This figure is shown that results of present study were placed between the curves of 36° and 50°. According to the apex angle of the present model, this result is acceptable.

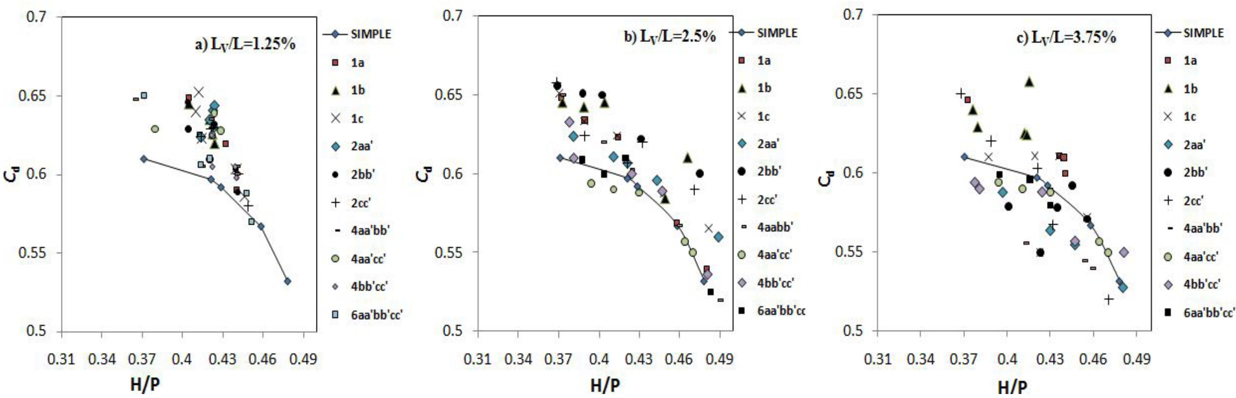

Fig7. Discharge coefficient of triangular labyrinth spillway against H/P for a) L_v/L=1.25%; b) L_v/L=2.5%; c) L_v/L=3.75%

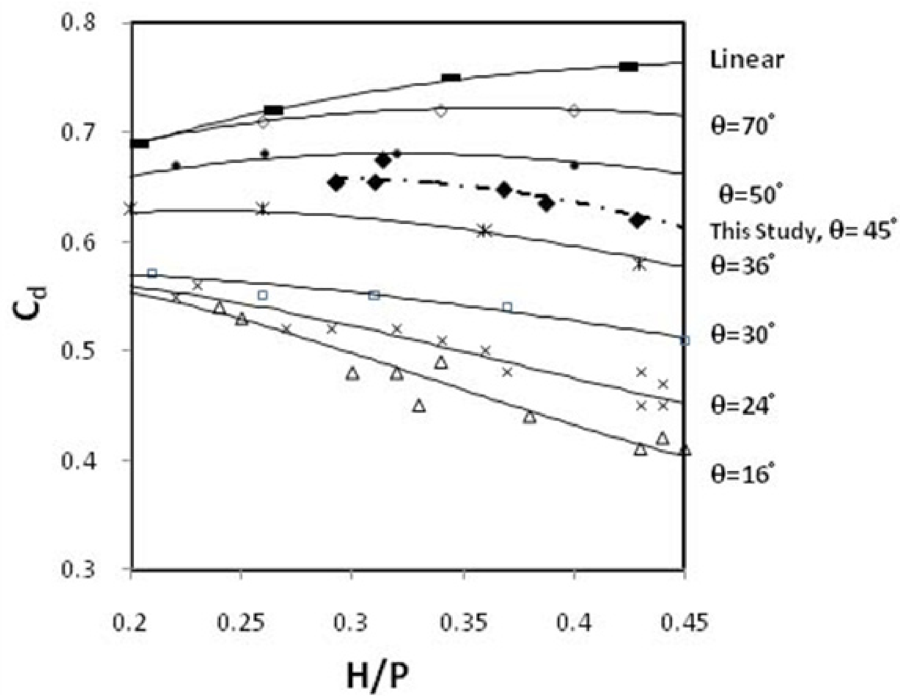

Fig8. Discharge coefficient of simple triangular labyrinth spillway: comparison of results of present study with Tullis et al. (1995)

For each test, the percent variation in the discharge coefficient computes from the below equation:

$$\text{Percent variation in } C_d = \frac{(C_{dv} - C_d)}{C_d} \times 100 \quad (7)$$

Where in, C_d = the discharge coefficient of simple triangular labyrinth spillway and C_{dv} = the discharge coefficient of guide vane triangular labyrinth spillway. For 3 ratios of L_v/L, results of variation in discharge coefficient show in Fig. 9. According to this figure, the maximum increment in discharge coefficient was equal up to 18%. With the increment in the ratio of L_v/L, the increment in the discharge coefficient was also reduced.

According to the Fig. 9 (graph a), it can be said that by increasing the amount of flow discharge, the increasing in the discharge coefficient is also higher. In other words, the effect of using the vane with 1cm width on the weir performance is more in higher discharge. Due to the Fig. 9 (graph c), the negative effect of the vanes with 3 cm width on the weir performance in low flow discharge can be found.

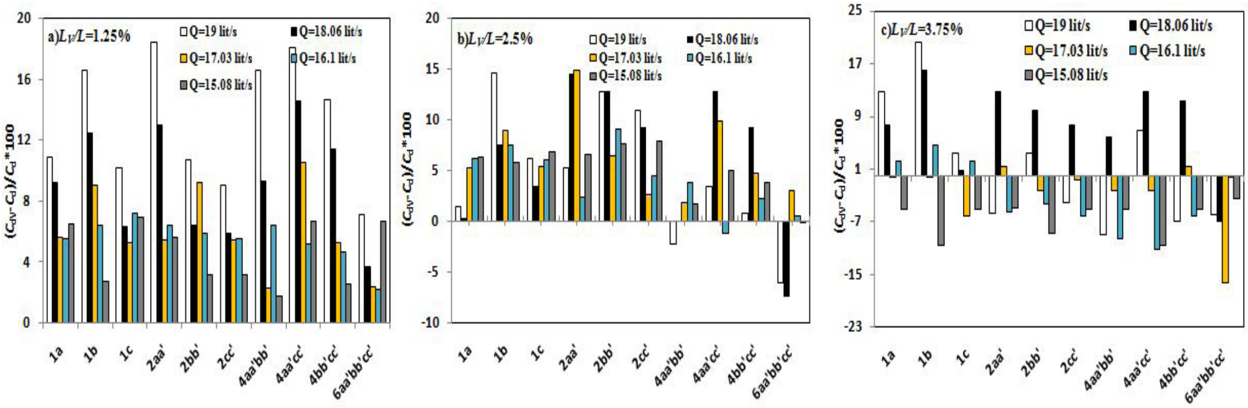

Fig9. Percent variation in discharge coefficient for a) L_v/L=1.25%; b) L_v/L=2.5%; c) L_v/L=3.75%

For 3 different numbers of vanes (*N*), the consequence of vane situation (*S*) on the discharge coefficient of triangular labyrinth spillway is displayed in Fig. 10. This figure reveals that for *N*=1, 2 and 4, 1*b*, 2*aa'* and 4*aa'cc'* models have the maximum discharge coefficient, respectively. Due to this figure, the consequence of *N* and *S* on the discharge coefficient of 6*aa'bb'cc'* couldn't be studied, because it was one model.

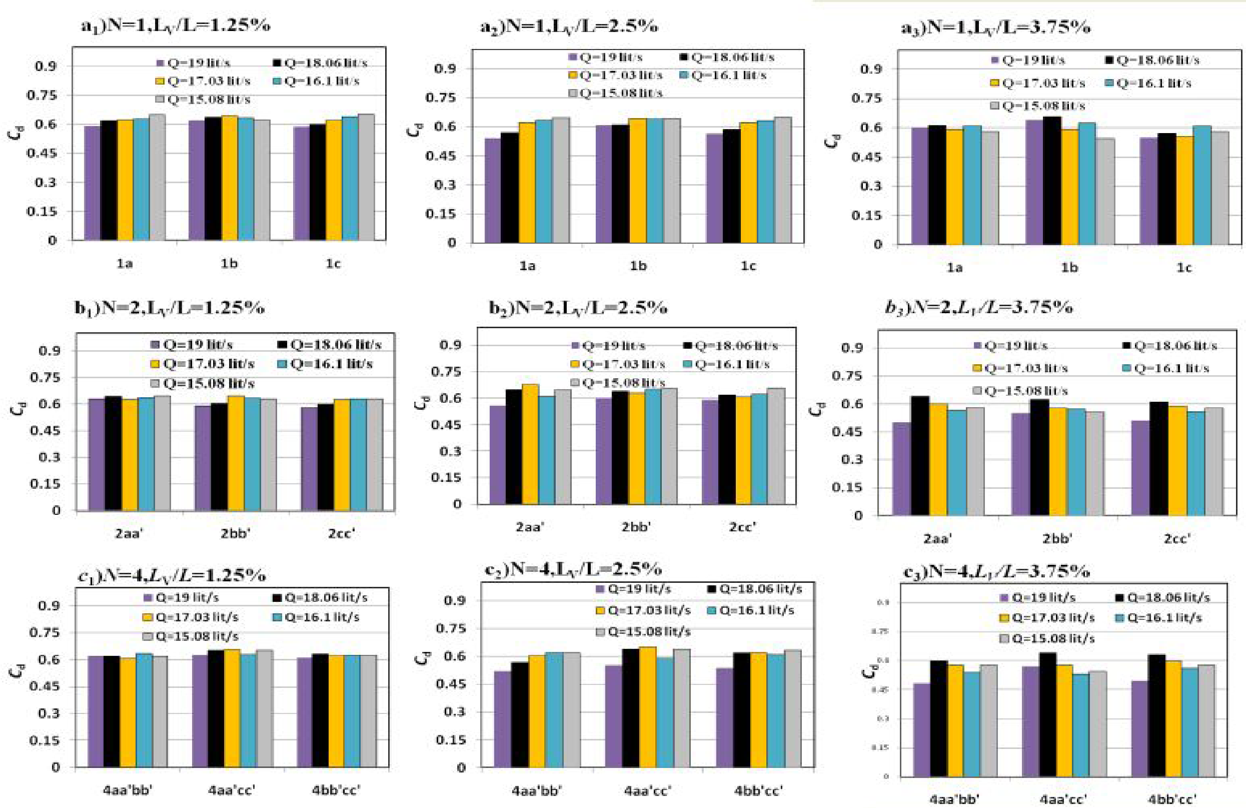

Fig10. The consequence of vane situation (*S*) on discharge coefficient of triangular labyrinth spillway for 3 different numbers of vanes (*N*)

As seen from Fig. 9, the maximum increment in the discharge coefficient was happened at L_v/L=1.25%. According to Fig. 10, the discharge coefficient of 1*b*, 2*aa'* and 4*aa'cc'* models was maximum. To specify the best model, the outcome of *H/P* on discharge coefficient of these 3 models is shown in Fig. 11. This figure reveals that 4*aa'cc'* model was the best model. This model can increment the discharge coefficient up to 18% (refer to Fig. 9).

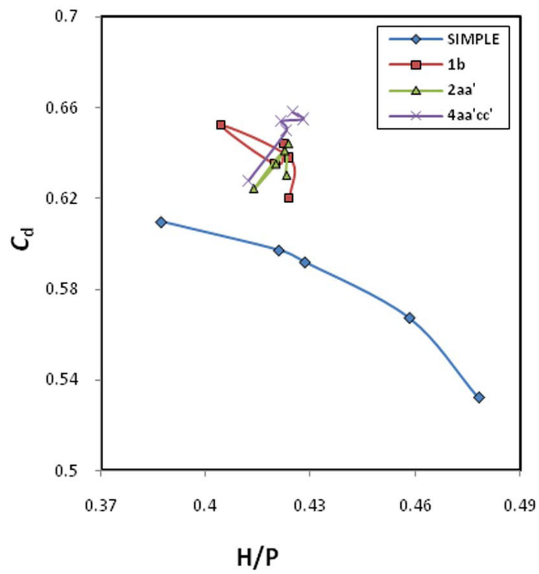

Fig11. The consequence of *H/P* on the discharge coefficient of 3 best models with L_v/L=1.25%

Conclusions

An experimental study conducted for investigation the guide vane consequence on the discharge coefficient of the sharp-crested triangular labyrinth spillway with an apex angle of 45°. Different configurations of guide vanes on the upstream face of the spillway were examined in a rectangular horizontal channel. The dimensionless parameter of *H/P* has more effect on the discharge coefficient of the spillway. In L_v/L=1.25%, the discharge coefficient was more than the discharge coefficient in other ratios. Also, utilizing 4 vanes in the first-quarter and fourth-quarter of two side legs can increment the discharge coefficient up to 18%. Streamlines over a triangular labyrinth spillway tend to deflect when they are passing over the spillway but not when perpendicular to the spillway plate. By using guide vanes at the upstream face of the spillway, the direction of flow could be controlled. Guide vanes are thin plates, when placed normal to the triangular labyrinth spillway, then the component of velocity over the spillway will be max. Hence, the discharge coefficient will increment.

Nomenclature

B Channel width (m);

C_d Discharge coefficient of simple triangular labyrinth spillway (-);

C_{dv} Discharge coefficient of guide vane triangular labyrinth spillway (-);

Fr Froude number (-);

g Acceleration of gravity (m/s^2);

H Total head over the spillway crest (m);

L Crest length of the spillway (m);

L_v Width of the vane (m);

P Spillway height (m);

Q Flow discharge (m^3/s);

R Reynolds number (-);

W Weber number (-);

μ Dynamic viscosity of the fluid ($N.S/m^2$);

ρ Density of the fluid (kg/m^3);

σ Surface tension of the fluid (N/m);

θ Apex angle (degree);

N Number of vanes (-); and

S Situation of vanes (-).

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