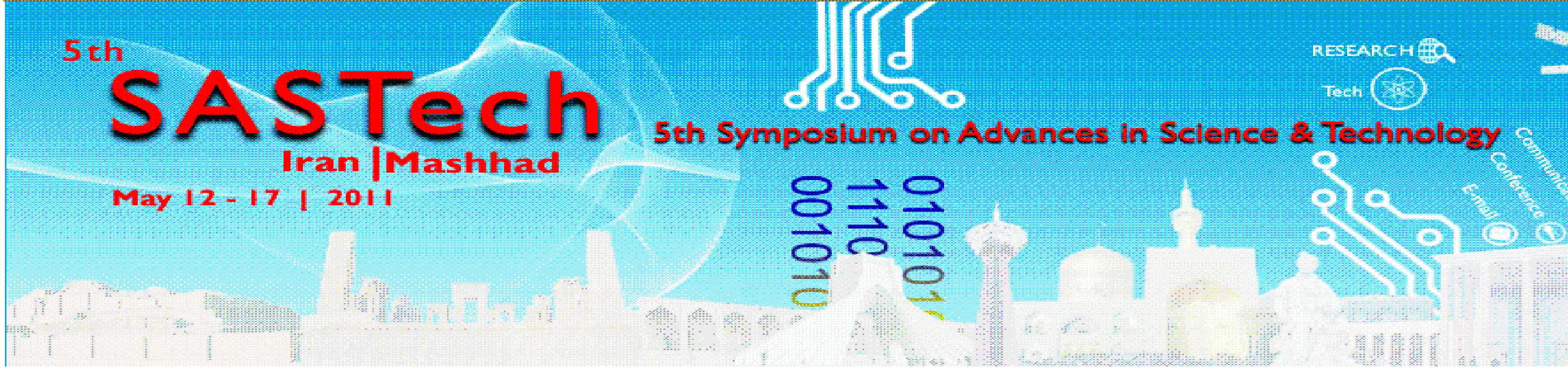

Experimental Study of Static and Dynamic Pressures over Simple Flip Bucket

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Abstract

Flip buckets are usually used in high head dams to dissipate the destructive energy of high speed jets. These structures are fixes at the end of the outlet conduits to direct the moving jet into the atmosphere. The process of energy dissipation also resumes, while the jet entering into its downstream plunge pool. Although studies of flow over flip buckets turn back to many years ago, but still there are uncertainties regarding the flow behaviour over these structures with various geometries and flow conditions. In this study, experimental measurements of static and dynamic pressures and their distribution over these structures are investigated. Measurements were made along two different simple flip buckets with various Froude numbers to determine the effects of the geometry and flow characteristics on pressure field. Maximum pressures are also presented and the results are compared with those of other investigations.

Keywords: Flip Bucket, Pressure Distribution, Dynamic Pressure, Physical Model

1. Introduction

Flip buckets are usually placed at the end of chute spillways and outlets of high dams to project the high velocity flows issuing from these structures. The outlet jet moves through the atmosphere and then enters into a plunge pool, which both help to dissipate the distructive energy of jet. Until 1950, the flip bucket design is often performed without considering centrifugal forces caused by flow rotation within the bucket. Generally speaking, the total pressure on the bucket is the sum of hydrostatic and the centrifugal effects in the forms of;

$$P = h_0 + \frac{h_0 V_0^2}{gR} \tag{1}$$

Balloffet in (1961) simulated the velocity distribution within flip bucket by irrotational flow hypothesis (*VR=Constant*) and then presented its pressure distribution as follows;

$$P_{\max} = h_0 + V_0^2 \big/ 2g(1-((R-h_0)/R)^2) \tag{2}$$

In the above equations, P_{max} is the maximum pressure, h_o and V_o are respectively the depth and velocity of entering flow to the bucket, R is the radius of the bucket and g is the acceleration of gravity. In (1963), Tierney and Henderson showed that for low values of h_o/R, the experimental results are in resonable agreement with those obtained from vortex potential theory with deflection angles less than *45°*. In (1965), Chen and Yu determined the pressure distribution along circular buckets using potential theory for deflection angles between *75°* to *95°*. Their results for maximum pressure were close to those of Balloffet. In (1969), Lenau and Cassidy modified Chen and Yu theory and gained a set of equations by assuming an incompressible and irrotational flow. They solved these equations to determine the pressure and velocity distribution within the bucket and showed that the effect of viscosity is insignificant, but the effect of centrifugal force is important. If the pressure (P) made dimensionless by Head of water (H) in the form of $P/\rho gH$, we have;

$$P\big/(\rho V^2/2) = (1/2)[P/(\rho g h_0)].[F_0^{-2}] \tag{3}$$

Where, $F_0 = V/(gh_0)^{1/2}$ is the entering Froude number of flow to the bucket, h_o is the water depth and R is the radius of bucket. Thus, the maximum pressure within the bucket is a function of its curvature, relative depth of water (h_o/R) and the entering Froude number of flow.

As was realized, so far, various models with different geometries of simple, complex, and inclined flip buckets have been studied. However, still systematic information should be collected to improve our knowledge on flow over these structures. Therefore, in this work, scaled models of left and right flip buckets of Gotwand dam in southern province of Iran were constructed and examined. The buckets are positioned at different altitudes. They are in circular shapes and longitudinaly straight (with no inclination). Their upstream chute spillways are rectangular with similar slope of *3.5%*. It was tried to determine a relationship between these parameters, based on experimental data from model studies of Gotwand dam. The results are then compared with those of previous investigation.

2. Data and Material

In Gotwand model, flip buckets are placed at the end of two chute spillways, each has *34.5cm* width and *2m* length. They are made of Plexiglass to visualize the flow pattern. The altitudes of the two buckets are different, but the radius of the buckets is $R=50cm$ and their curvature angle is $\beta=28°$. Figure (1.a) presents the hydraulic model of Gotwand dam and Figure (1.b) demonstrates the geometry characteristics of the left bucket.

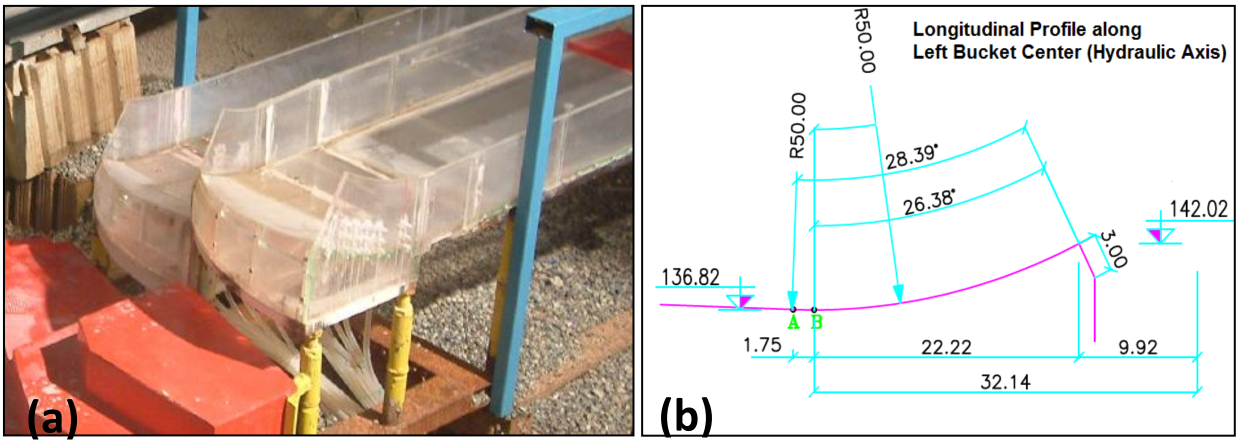

Fig 1: (a) Gotwand hydraulic model of the flip Buckets; (b) Geometry characteristics of the left bucket

Measurements of pressure on the bucket were made with different discharges (from *20-120 lit/sec*). As a result, the mean velocity and depth of entering flow (h_o) varied and thus, the entering Froude number changes from $Fr=3.5$ to *7.5*. A set of pressure tubings were fixed at different cross sections of the buckets to measure the pressure. It includes the centerline and close to the walls. Figure 2 shows the position of these pizeometers on the two buckets.

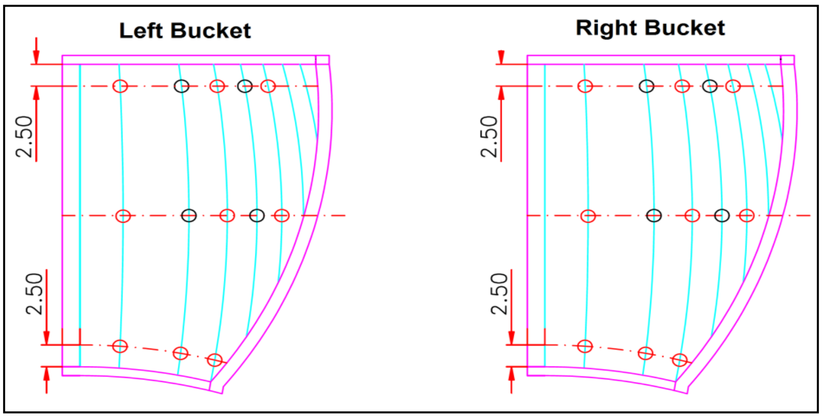

Fig 2: Position of pizeometers on the left and right scaled models of the buckets

After the measurements, determination of static and dynamic pressure distribution on the bucket is an important task, which is used to design and check the stability of such structures. Different flow patterns which may be distinguished in the bucket are shown in Figure 3. These include of hydraulic jump (Fig 3.a and 3.b) or free jet (Fig 3.c) performing on the bucket.

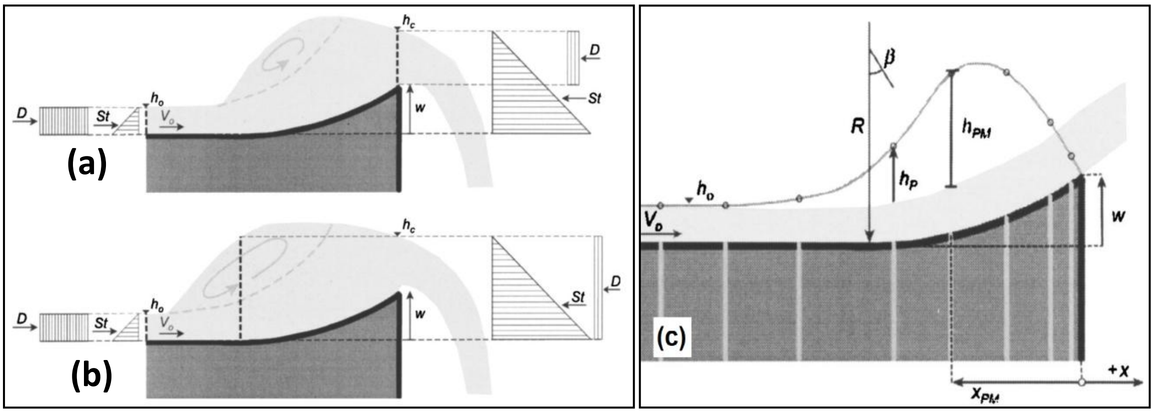

Fig 3: Static and dynamic pressure caused by hudraulic jump or free jet on the bucket

Figures (3.a) and (3.b) show the variations of pressure in hydraulic jump and Figure (3.c) presents the dynamic pressure distribution and the position of its maximum on the bucket. Figures 4 and 5 show the experimental results of static and dynamic pressure upstream (on the chute) and on the bed of the left and right buckets, respectively. As the static pressure is a function of flow depth, it is possible to measure and calculate both static and dynamic pressures on the bed and the side walls. However, attention has been given to present the dynamic pressures. In Figure 3 rapid variation of Pressure distribution on the buckets is distinguished.

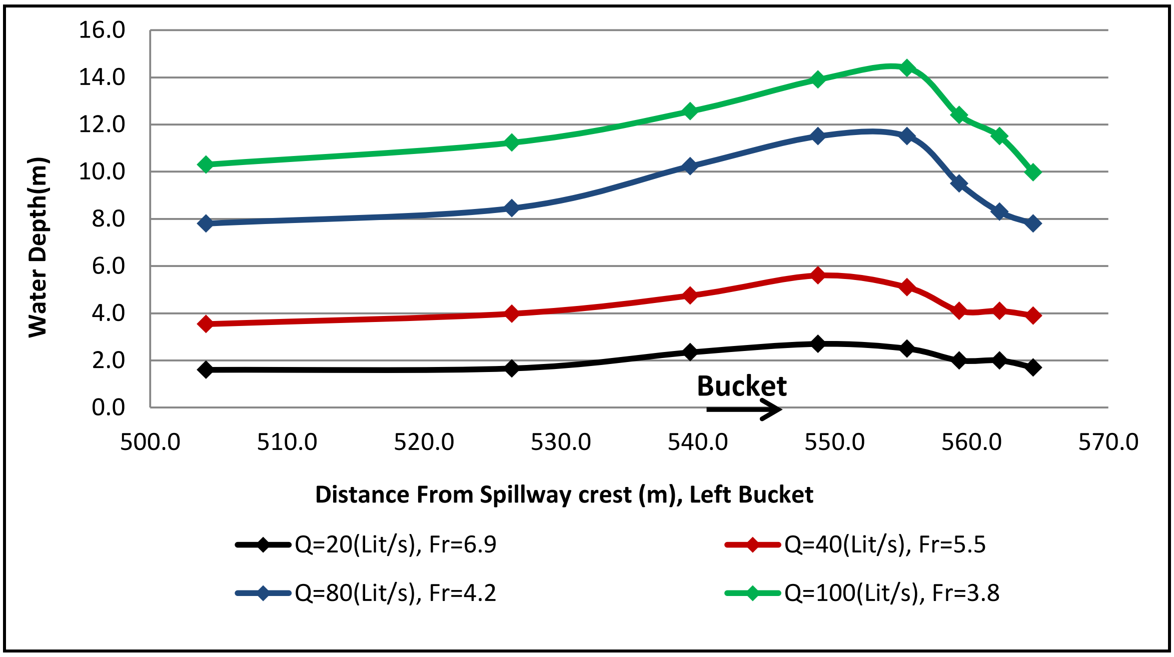

Fig 4: Variation of dynamic pressure on the left bucket of Gotwand dam

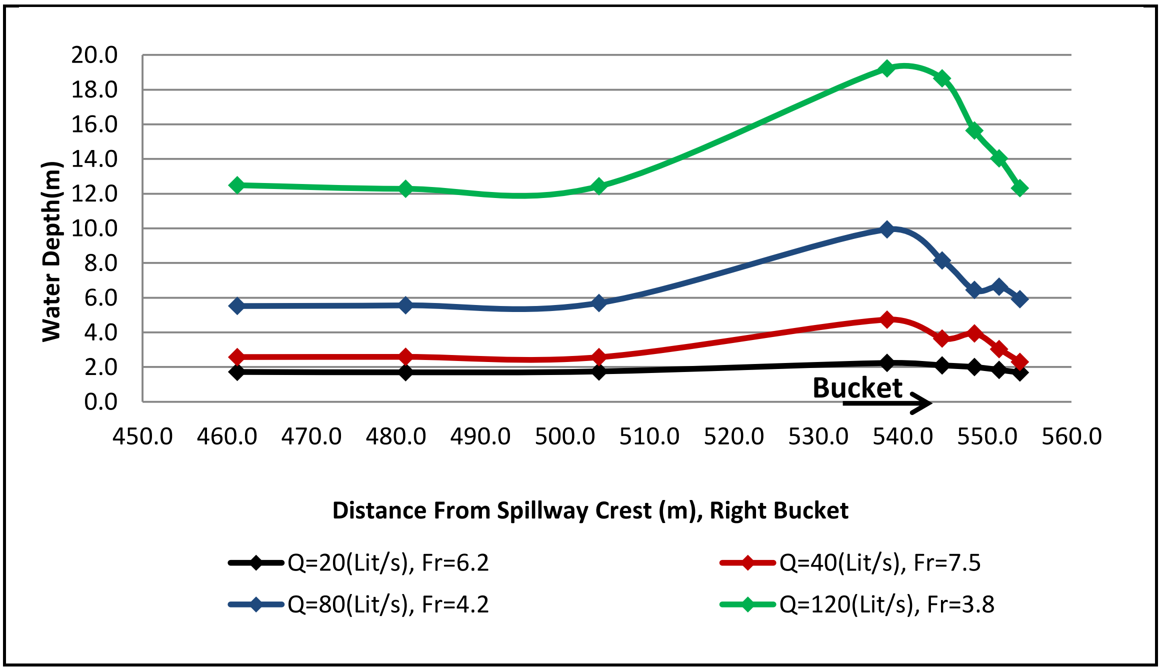

Fig 5: Variation of dynamic pressure on the right bucket of Gotwand dam

3. Results and Analysis

To present the results, a dimensionless parameter, H_p, was introduced in the following form, which its distribution on the bucket can be presented based on the bucket geometry and its hydraulic characteristics;

$$H_P = (h_P - h_0) / (h_{PM} - h_0) \tag{4}$$

Where, h_p, h_o and h_{PM} are respectively the longitudinal total, static and maximum pressures on the bucket. Therefore, the results of H_p with $X_p=x/(R.Sin\beta)$, which is a dimensionless form of distance x can be presented. The dimensionless form is a function of the bucket radius R and its deflector angle. The position $x=0$ represents the lip of the bucket, where the jet leave the bucket and $R.Sin\beta$ represents the length of flip bucket. Figure 6 presents the data scatter of the results for H_p against X_p along the centerline of the bucket. Based on the experimental results, the best form of relative pressure variation was found by equation 5.

$$H_P = [-1.5X_P \exp(1+1.5X_p)]^{2.3} \tag{5}$$

In this equation, pressure variation H_p along the centerline of the bucket in equation 5 is independent of entrance Froude number F_o, but the effect of water depth h_o and the geometry of the bucker (R and β) are important. At the beginning of the bucket where $X_p=-1$, the pressure parameter is about $Hp\approx 0.5$. The figure shows that the effect of the bucket on pressure domain extends upstream on the chute to a distance of $X_p=-3$, which should be considered as inflow boundary conditions of the bucket. For condition of $X_p<-3$, the pressure parameter can be regarded as $H_p=0$.

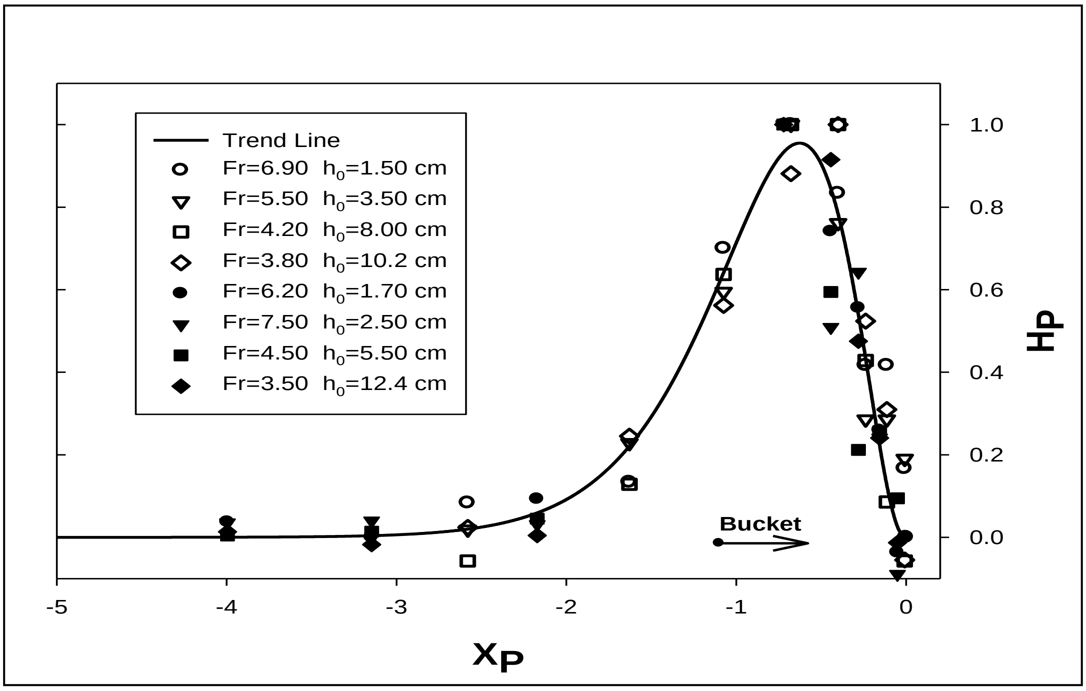

Fig 6: Variation of dynamic pressure *Hp* along the centerline bed of the bucket X_p ($r^2=0.91$)

The present information has been compared with those of previous investigations to check and validate the results. Dynamic pressure distribution based on experimental studies of Joun and Hager (2000), which is independent of Froude number F_0, was expressed by the following equation.

$$H_P = [-2X_P \exp(1+2X_P)]^{2/3} \tag{6}$$

Also Heller et al. (2005) studied the dynamic pressure distribution based on physical models of different hydraulic and geometry characteristics. They introduced the following equation;

$$H_P = [-X_P \exp(1+X_P)]^{1.5} \tag{7}$$

The forms of Equations 6 and 7, which show the dynamic pressure distribution along flip buckets are in reasonable agreement with the present study as given by Equation 5. The result of Joun and Hagger (Eq. 6) is based on experiments with *R=20cm* and *25cm*, while the present study is based on *R=50cm*. The proposed Eq. 7 by Heller et al. is better agreed with the present expression, due to their closer hydraulic and geometry characteristics of the experimental information. However, their equation is based on *R=40cm* and various geometry and hydraulic characteristics, which gives a low determination coefficient ($r^2=0.56$) for high radius. As a result, the present expression of pressure distribution is a resonable suggestion for flip buckets of high radius.

4. Conclusion

The results of this paper are based on experimental information collected from two flip buckets of Gotwand dam in Iran. The results show that upstream from the bucket, the pressure distribution starts increasing from hydrostatic values to a maximum h_{PM} and then reducing to $h_p=-h_0$ at the end of the bucket. Based on the present results, a new expression was introduced for dynamic pressure distribution along the centerline of the bucket. Equation 5 presents the pressure distribution as a function of flow depth h_o and bucket geometry (radius *R* and deflector angle β). This expression is based on experiments carried out with buckets of high radius, thus the result is suggested to be useful for such geometries. Therefore, by using Fig. 6 or Eq. 5, the position of maximum dynamic pressure on the bed of flip buckets with high radius can be determined. The form of this equation is in general agreement with those of previous expressions. However, the differences show the importance of geometry characteristics on pressure distribution within the flip buckets.

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