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Experimental and Numerical Study of the Effect of Flow Sepration on Dissipating Energy in compound Bucket

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Abstract

In this research by making tree different buckets, separation effect has been analyzed. First model was a bucket with lip angle of 40 degrees and the two others were compound bucket which have two equally division in bucket width with different lip angel in each part; one of them has 20, 40 degrees angel and another one has 40, 80 degrees. The major amount of energy dissipation occurs in the region where the jet plunges into the tailwater; So the hydraulic jump sequent depth is used to evaluate energy dissipation at downstream. Experimental results showed that the compound bucket with less lip angle is more efficient. Also this paper discusses two and three-dimensional numerical modelling of bucket configurations using the CFD software Flow-3D and compares the fluid depth curves and Energy loss to corresponding physical model experimental values. The numerical model results were generally in agreement with physical model data.

Keywords: Physical model, FLOW-3D, Energy Dissipation, Flip bucket spillway

1. Introduction

Spillway and discharge channel of reservoirs require the Control of Large volume of water under high pressure. The energies at the downstream end of spillway or discharge channel are tremendous. Therefore, some means of expending the energy of the high-velocity flow is required to prevent scour of the riverbed, minimize erosion, and prevent undermining structures or dam itself. There are many types of energy

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dissipators and one of the energy dissipaters is known as flip bucket [1]. The purpose of the flip bucket is to direct high-velocity flow (the jet) well away from the dam, powerhouse, spillway, and/or other appurtenances. A small amount of energy is dissipated by friction through the bucket. The extreme turbulence of the jet entrains a large volume of air. A portion of the jet's energy is dissipated by the interaction of the water and the air boundary resulting in considerable. As a result, use of a flip bucket should be considered only where bed scour caused by the impact of the water jet cannot endanger the dam, power plant, or other structures (including the flip bucket itself) or cause unacceptable environmental damage. Where the flip bucket can be appropriately used, it offers an attractive economical alternative to a stilling basin or roller bucket structure. In general, flip buckets are designed with horizontal rectangular cross-sections. Theoretical analysis, experimental studies and practical experiences have helped in setting up the vast amount of existing guidelines to calculate the bucket profile, elevations, radius and exit angle. Special bucket shapes are sometimes designed, as laterally inclined or slanting ones, to modify the jet trajectory and its compactness [2], [3]. Splitters can also be placed on the flip bucket to divide the jet and thus to improve the energy dissipation, in order to limit the downstream scouring [2], [4]. However, such nonstandard geometries need usually to be designed and validated by experimental modeling and scale models studies. In this study discusses two and three-dimensional numerical modelling of three different bucket configurations. The commercially available CFD model Flow-3D version 10.0.1.3 software that was developed by the Flow Science was applied. This is rather satisfactory software for the solutions of equations that represent the free surface turbulent flow. The fluid depth curves, Energy loss and water surface elevations were compared to corresponding physical model experimental values. Results showed that the numerical model and physical model are in reasonably good agreement with one another. From 1933 till 1954, United State Bureau of Reclamation (USBR) regarding to hydraulic model tests, covered a complete range of bucket sizes and tail water elevations, were conducted to verify the bucket dimensions and details and to establish general relations between bucket size, discharge capacity, height of fall, and the maximum and minimum tail water depth limits. Vischer and Hager (1998) proposed that flip buckets are used when energy has to be dissipated for a flow velocity larger than about 15–20 m/s. Savage & Johnson (2001) used Flow3D to compare its results of ogee spillway flow with those of a physical model. Roman Juon and Willi H. Hager (2000) and Valentin Heller et al. (2005) and Remo Steiner et al. (2008) performed some investigations on flip buckets, including scale effects in hydraulic models, bucket pressure distribution, and nappe trajectories with and without the presence of deflectors. Schmocker et al. (2008) studied aeration characteristics of ski jump jets. Erpicum et al. (2010) had investigated on the effect of bucket splitters on plunge pool geometry. Zhang and Wang (2013) had studied on a new-type dissipater, named allotypic hybrid-type flip bucket, which combined the advantage of diffusion flip bucket, slit-type flip bucket and hybrid-type flip bucket together.

2. Experimental Set Up

The experiments have been conducted in the laboratory of hydraulic models in the Islamic Azad University of Marvdasht in flume with 8 meters length and 50 cm width and 1 m height in the first 3 meter and 50 cm height in remaing. This flume includes the main faucet to adjust the flow discharge and the calmative reservoir. The triangular weir was used for measuring discharge. The physical models were constructed according to Froud similitude and were prepared following the standards for Ogee spillway design required by the United States Bereau of Reclamation (USBR) with the 80 cm height and the 23 cm bucket radius. Three flip bucket models were built. The first one was a continuous flip bucket with 40 degree lip angle (model 1) and two others were compound, their bucket were divided into two equal parts in cross-section and each one with different lip angel.one with 20 , 40 degrees (model 2) and the other one had 40, 80 degrees lip angels (model 3). Water is injected in an upstream tank and flows over the weir to produce specific discharges in the channel ranging from 0.8 lit/(s) to 33.9 lit/(s). Eight experiments were done on model 1 as references and twelve others were done on model 2,3. Therefore, overall 32 experiments have been conducted in the present study. In each run the depths were measured in six sections. The first depth of hydraulic jump after ski jump, the second depth was calculated using conjugate depth equation for rectangular section. Further, the energy in the upstream and downstream of the spillway was calculated from Bernoulli equation. Then, the observed energy dissipation was compared with the corresponding observed energy dissipation from reference experiments (continuous flip bucket). To done the experiments, first the model was set to an ideal position, next the pump was started and the flow was led into flume then the discharge was adjusted by the main faucet of the discharge. Increase in tail water depth was partly allowed so that the hydraulic jump would take place slightly after the jet impact to the bottom of flume, then the desired variables were measured. In each run these measurable variables were measured: discharge, y1, y2 (sequent depth of hydraulic jump), the height of the water on spillway, jet trajectory and upstream depth. The y1 and y2 represented the depth before and after the hydraulic jump respectively. All above steps have done for two other tail water depth. In explained case, that the ski jump takes off and then Impact to bottom of flume and hydraulic jump occur completely free and stable.

3. Numerical Model Set Up

The commercial software Flow-3D was used for the numerical modeling of the flow. This package is a finite difference/volume, free surface, unsteady flow modeling system, developed to solve the Navier-Stokes equations in three dimensions. Flow-3D uses an orthogonal coordinate system as opposed to a body-fitted system and can have a single nested mesh block, adjacent linked mesh blocks, or a combination of nested and linked mesh blocks. The geometry was generated using AutoCAD, based on the dimensions of the physical model; it was then imported into the code as an STL file. Under the General sub-tab, Simulation unit was selected the CGS. In Physics, the gravity option was activated with gravitational acceleration in the vertical or z-direction being set to negative 980.6 . The viscosity and turbulence option was also activated with Newtonian viscosity being applied to the flow along with the selection of two-equation (k-e) turbulence model. Air entrainment, Density evaluation and Scalars were active. Boundary conditions which were employed in this investigation are shown in Figure 1-a. For each experiments were done in laboratory, made individual simulation and got output curve to compare with experimental result.

4. Results and Discussions

4.1. Jet trajectory:

The results show that bucket with 20º,40º lip angles has better operation than 80º (Fig 2-a). Because according to the observations, in bucket with 80º lip angle, water volume that gathered in the bucket need more power and velocity for exiting the jet in low discharges therefore it has low efficiency. In the bucket with 20º,40º lip angle up to 10.78 lit/sec jet from 20º bucket was farthest but from 11.56 lit/sec each two jets almost gather together until two jets become same completely, therefore the discharges that has been divided in two pieces unify again. The longest jet trajectory was 0.945m in the maximum discharge. By studying buckets, it is obvious that up to 7.13lit/sec discharge, there is no exiting jet and the start point is 8.24lit/sec and in has the maximum length in the maximum discharge. However, in the bucket with 40º exiting angle it occurs from the beginning and in compare of 80º bucket in the same discharge it has longest jet. Therefore 40º bucket has better operation. In these examination jet velocity was less than 20m/sec, therefore according to the Kawakamy theory(1973) air resistance has less effect and on the jet passing distance has no considerable effect (javan and Hauger (2000)).

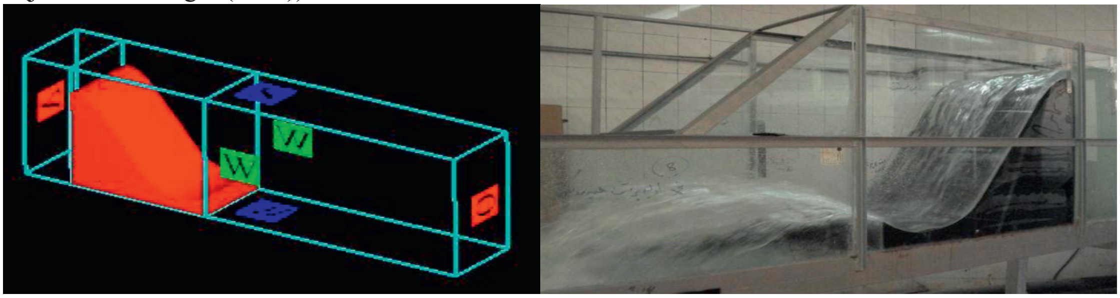

Fig. 1 .(a) Boundary Condition; (b) model 2.

4.2. Energy loss between weir and bucket lip

For different sections, energy loss changes have different process in compare of discharge, but according to the most graphs, most loss occurs for low discharge and also in the higher discharges energy loss decrease. According to the drawn curve, less energy loss obtained for 80º bucket in the 23.76lit/sec discharge and it was equal to 0.0176. Most loss occurred in 20º bucker in 10.36lit/sec discharge and it was equal to 0.793. Totally, it can be said energy loss changes process has sinusoidal mode in compare of discharge and most energy loss happened in 20º model (Fig 2-a).

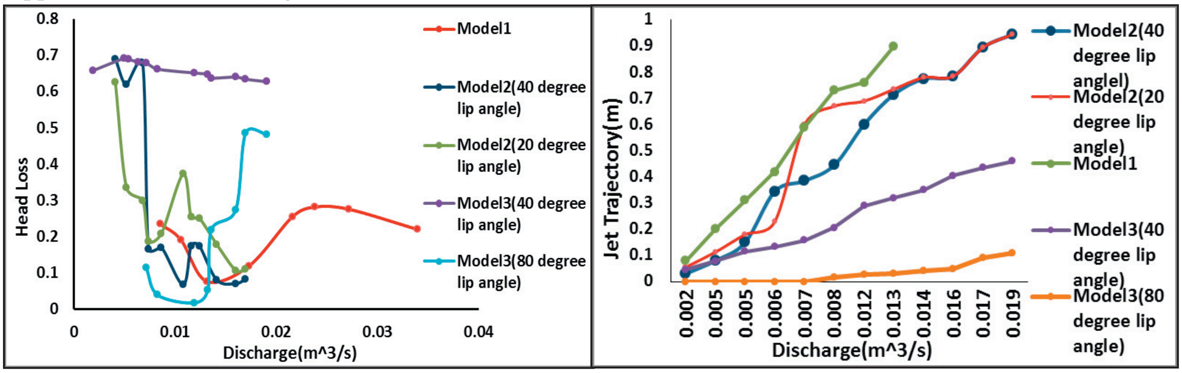

Fig. 2. (a) Energy loss between weir and bucket; (b) Jet trajectory

4.3. Overall system loss

By comparing each three models, observed that (Fig. 3) 20º and 40º bucket has more energy depreciation ratio, better operation and more efficiency than the two others. Because in the 40º&80º combination we observed that in the primary examination steps and in the low discharges 80º bucket couldn't throw the water out of bucket therefore total water volume gather on the 40º bucket and it caused decreasing overall system loss. continuous flip bucket, conduct input flow to the top and causes boiling surface creation and subsequently flow plunge into the bucket downstream that causes more scour because outgoing flow from this structures has a compact water core therefore it can't be totally separated in the air so it has low efficiency as an energy depreciator. Therefore because of 20º,40º bucket better operation solid and suspended materials wash away from bucket while in 40º,80º bucket this operation is so weak. 80º bucket flip height causes turbulence and prevent accurate water depth measurement. In addition, cluttered and asymmetric flow jets formation causes system operation decreasing in energy depreciation. According to these observations can infer that curvature radius of jet structure shouldn't be so large that it's wall prevent from flow exit.

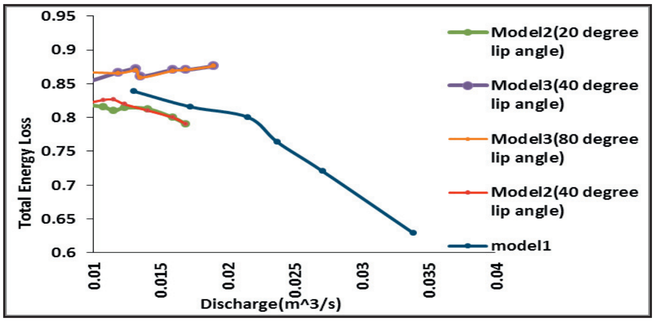

Fig. 3. Overall system loss

5. Conclusions

1- Major angles are efficient in high discharges, they cause jet longer passing distance and prepared better conditions for energy depreciation and cause jet plunges in to the tailwater with smaller angle. Therefore horizontal jet velocity component increases in the plunge point and scour probability increase, and cause longer plunge pool therefore project cost increase. Using smaller angle causes jet plunges into the tailwater approximately vertically. Therefore, vertical velocity the best domain is 20º to 40º as we observed in model 2.

2- Curvature radius of jet structure shouldn't be so large that it's wall prevent from flow exit because it cause asymmetric exiting jet occurs therefore energy operation decrease seriously.

3- In the continuous flip bucket outgoing flow has a compact water core, therefore it cannot be totally separated in the air and therefore it has low efficiency as a energy dissipator. Compound bucket dissipate flow energy on the bucket and causes less flow centralization.

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