2013, Scienceline Publication

Journal of Civil Engineering and Urbanism

Volume 3, Issue 2: 56-61 (2013) (Received: February 10, 2013; Accepted: February 28, 2013; Published: March 30, 2013) ISSN-2252-0430

Effect of Wedge Shape Deflector on Dissipating Energy in Triangular Flip Buckets

M. Omidvarinia[1] and S.H. Musavi Jahromi. [2]

[1]*Ph.D student of hydraulic structure in water science faculty of Shahid Chamran University*
[2]*Associated professor in water science faculty of Shahid Chamran University*

[*]Corresponding Author's E-mail address: mona_omidvarinia@yahoo.com

ORIGINAL ARTICLE

ABSTRACT: Ski jumps are a major element of each dam spillway because these are the only structures able to accomplish satisfactory energy dissipation for takeoff velocities in excess of some 20 m/ s. When water flows over spillways or the dam bottom outlets, flow has a height velocity. In such conditions it has a lot of kinetic energy. In order to dissipate this destructive energy, energy dissipater should be constructed. If geology condition in downstream is appropriate, flip bucket can be used, particularly for height dams. This structure to loss kinematic energy is a cheap method and safer than other ordinary energy dissipaters such as hydraulic basins and roller buckets to employ deflector, is one way to increase energy dissipation in this structure. Deflector is a wedge-shaped structure which creates changes in part of flow trajectory. To investigate the effect of deflector on energy dissipation, an experimental setup has been developed in the Hydraulic Laboratory of Shahid Chammran, Iran. In this research program, the 45 degree bucket with 7 cm approach channel at the end of ogee spillway was divided into two trajectories by deflector. Data analysis showed that the clash between these two trajectories increases energy dissipation in flip bucket. Maximum observed energy dissipation was 70.3% that it occurred in the Froude number 6.7, deflector angle of 25 degree and the side with 12-cm-length.

Keywords: Energy Dissipation, Flip Bucket Spillway, Deflector, Physical Model

INTRODUCTION

The Ski jump dissipation of flow kinematic energy is an important matter in downstream of dam. The most common methods to dissipate energy are the stilling basin which employs the hydraulic jump for energy dissipation, the roller bucket which achieves energy dissipation in surface rollers over the bucket and ground rollers downstream of the bucket, and the flip bucket which deflects the flow downstream, thereby transferring the energy to a position where impact, turbulence, and resulting erosion will not jeopardize safety of the dam or appurtenant structures. It should be noticed that Flip buckets are used when energy has to be dissipated for a flow velocity larger than 15–20 m/s , there is the possibility of cavitation and uplifting force in downstream structures. Nowadays flip buckets are used widely around the world because of its acceptable reliability in the field of energy depreciation. The flip bucket itself is not an energy dissipater however; it is an integral part of an energy dissipation system. 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. During the jet's trajectory to its impact location, extremely turbulent flow exists and the jet spreads and frays. 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 spray. The effect of heavy spray on adjacent structures, especially in cold regions, should be considered. Impact of the jet and the interaction of the turbulent flow and the boundary at the impact area account for the major portion of energy dissipation. The impact will almost certainly cause adjustment to the riverbed even if the bed material is rock. 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. However, the flip bucket includes more uncertainties as to adequacy than do stilling basins or roller buckets.

Ski jumps were successfully introduced in France on the Dordogne hydraulic scheme, as early as the mid-1930s (Godon1936; Coyne 1944, 1951; Auroy 1951) with detailed prototype observations conducted on the jet flow by Maitre and Obolensky (1954). Rhone and Peterka (1959) studied an improved design of flip buckets implemented by the U.S. Bureau of Reclamation (Peterka 1983). Pressures on buckets were computed and observed by Balloffet (1961). Using a potential flow model (i.e., concentric streamlines in the bucket), he found that the maximum pressure head is on average 4% larger than computed provided the ratio of flow depth ho in the bucket to its radius R of curvature is relatively small. Henderson and Tierney (1963) demonstrated that, for small ratio ho/R of the potential vortex approach, the 2D computation and observations agree provided the deflection angle is at least 45º. Chen and Yu (1965) computed the pressure distribution along a cylindrical bucket by using the potential flow equations for deflection angles of b =75˚ and 95˚. The maximum pressure heads are close to those of Balloffet's approach.

Lenau and Cassidy (1969) improved the approach of Chen and Yu (1965). They demonstrated that the effect of viscosity in bucket flow is insignificant. The effect of gravity is important, however, involving the parameter Q/(2gH)1/2R, where Q = discharge, and H = energy head. Because the static head is small compared to the dynamic head V2/2g, one may also express their term as ho/R. Moreover, their dimensionless pressure p/(ρgH), where g = gravitational acceleration, and ρ = fluid density, may be expressed as p/(ρV2/2). If the pressure head is related to the approach flow depth ho, one would have p/ (ρV2/2) = (1/2) [p/(ρgh0)].[F0-2], where Fo = V/(gho)1/2 is the bucket Froude number. Maximum pressure thus depends on relative bucket curvature ho/R and bucket Froude number Fr. In the following, a simple combination of the two parameters is presented.

Rajan and Shivashankara Rao (1980) summarized prototype findings on ski jump flow. A common design standard is described such as cylindrical bucket shape, flip angle between 20˚ and 40˚,Bucket height to bucket radius of the order 10-1, bucket radius as a function of specific discharge and bucket velocity, bucket lip designed against cavitations damage, tail water elevation well below bucket,

Another summary of guidelines was also presented by Mason (1993). His additional recommendations are as minimum bucket radius three to five times the approach flow depth, maximum pressure according to (2), with s = 1, free board of side walls by accounting for the air-water flow bulk age, lip angle or takeoff angle between 20˚ and 35˚, spread angle of jet in air about 57˚, splitter teeth not recommended because of cavitations risk, Scour characteristics not considered.

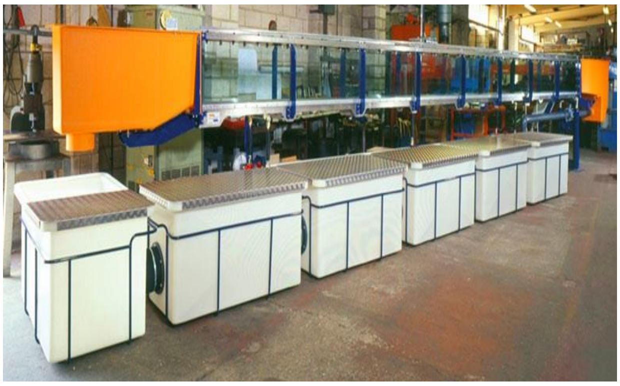

Figure 1. Longitudinal profile of the experimental flume

These considerations were also summarized by Vischer and Hager (1995) and accounted for in the design of the present model study. Juon and Hager (2000) had studied on flip bucket with and without deflector. Heller et Al. (2005) had researched on ski jump hydraulic completely. Nor Azlina et al. (2008) had investigated on impact of takeoff angle of bucket type energy dissipater on scour hole. Steineret al. (2008) had studied on Deflector ski jump hydraulics. Schmocker et al. (2008) studied aeration characteristics of ski jump jets.

MATERIALS AND METHODS

The experiments have been conducted in the laboratory of hydraulic models in the Chamran University of Ahwaz in flume with 15 meter length and 30 cm width and 50 cm height (Figure 1).

This flume includes the main faucet to adjust the flow discharge and also a digital flow meter of 0.01 liter per second accuracy before the flow's entry to the calmative reservoir for measuring discharge and a valve in a lower part to adjust the tail water. The LDV is utilized to measure the velocity of the flow in different levels and to measure the profile on the surface of the water the point gage with 0.0005 meter accuracy is used. Figure 2 shows applied measurement instruments.

An ogee spillway was built based on the standard USBR with the 33 cm height (Figure 3). The bucket was built with 7 cm approach, 9.7 cm height and 45 degree angle (Figure 4and 5). Then, the flip bucket was attached in 5.39 meter far from the reservoir. The deflectors used in this study are wedge-shaped with 30 cm height with isosceles triangles segment with the sides of 6cm, 9 cm and 12 cm and angles of 25˚ (Figure 6).

The deflectors are attached in a height of hmax/2 from the bottom of bucket. hmax is the water depth for maximum discharge. The position of the attached deflectors is 2 cm away from the bottom of the bucket, and the bottom of the bucket is 2 cm higher than the bottom of the flume (Figure 4).

In any stage the deflector with a certain lenth was attached in a way that the lower side of deflector was paralleled with bed of the experimental flume. Experimental scenarios were conducted using 4 discharges including; 10, 15, 20, 25 liter per second and 3 tail water depth 100%, 85% and 70%. . For any selected discharge, 3 different lengths of deflector and 25 degree angels related to each length were tried. Moreover, 12 experiments were done with no deflectors as references. Therefore, overall 48 experiments have been conducted in the present study.

In each run the depth and the velocity were measured 1 meter before the spillway in the upstream. Due to difficulties for measurement of the flow depth downstream of the trajectory, a hydraulic jump was formed downstream using a slide gate. The depth after ski jump, immediately before hydraulic jump, 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 (spillway without deflector).

The flow was turbulent and was located in the area of the rough bed, since in all experiments the Reynolds number was more than 2000, the shear Reynolds number was more than 200 and the water's depth on the crest of the spillway was more than 5 cm,. The effect of viscosity and the surface tension were so poor that they were neglected.

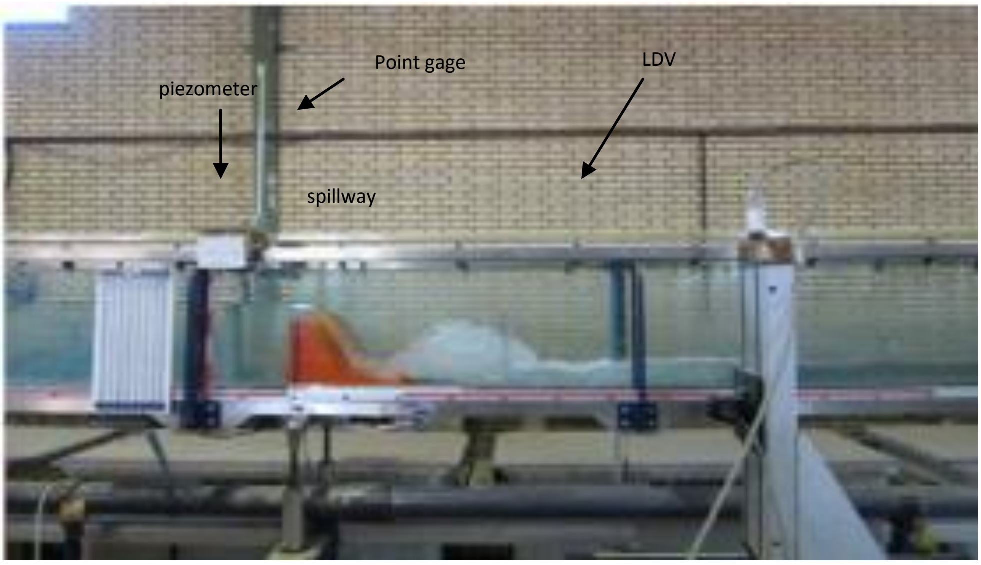

Figure 2. Location of measurement instruments along the flume

Figure 3. Ogee spillway

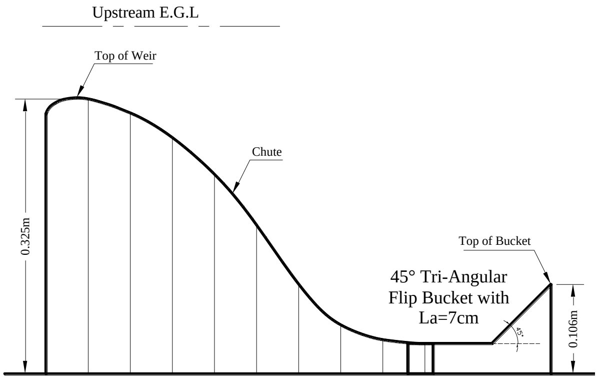

Figure 5. Longitudinal profile of ogee spillway and triangular flip bucket

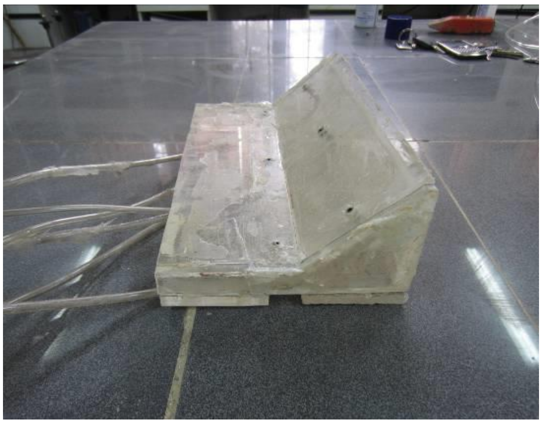

Figure 4. Triangular FlipBucket

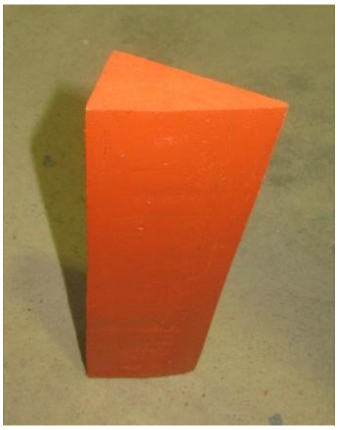

Figure 6. Wedge shape deflector

EXPERIMENTS

To done the experiments, first the deflector was attached 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. Under these conditions the downstream valve was completely opened and after accurate regulation of discharge, the downstream valve was gradually closed just to increase the depth of tail water. 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 2 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. This stage called 100% tail water because ski jump has 100% of its length. After all measurements in first stage, tail water depth increase with bottom flap gate , and hydraulic jump move toward upstream until it occupy 15% of jet length this stage called 85% tail water because ski jump has 85% of its length and also all the data have taken in this stage. In third stage , tail water depth again increase with bottom flap gate , and hydraulic jump move toward upstream until it occupy 30% of jet length this stage called 70% tail water because ski jump has 70% of its length and also all the data have taken in this stage.

RESULTS AND DISCUSSIONS

The results of analyzing data have been presented in the figures and the table quantitatively and qualitatively. The term $\frac{\Delta H}{H0}$ indicates the energy dissipation and Fr is the approach Froude number in flip bucket. As it can be seen in Figure 7, the observed maximum energy dissipation in experiments without deflector is 61.6% which is corresponded to Froude number 6.5 and the minimum percentage of the energy dissipation is 30.54 and it occurred in the Froude number 4.46. Increasing the Froude number would result to Increase the amount of the energy dissipation. On the other hand, dissipating energy in 100% tail water is maximum and in 70% tail water is minimum, because in case 100%ski jump occur completely and impact will dissipate most energy but in 85% and 70% Impact did not occure and they dissipate less energy.

Figure 8 shows the relationship between dissipating energy and relative depths of hydraulic jump. As it shown increasing the y2/y1 would result to decrease the amount of the energy dissipation, so by increasing the tail water depth dissipating energy would decrease.

Table 1. Dissipating energy for experiments without deflector

tail water %	H_0 m	h_1 m	h_2 cm	h_3 m	Fr_1	Fr_2	H_1 m	□H_1/H_0 %
100	0.40	0.0447	15.7	0.045	2.81	0.43	0.222	44.93
100	0.39	0.0378	13.7	0.038	2.89	0.42	0.196	49.22
100	0.37	0.0317	11.2	0.032	2.83	0.43	0.159	57.08
100	0.35	0.0224	9	0.022	3.18	0.39	0.135	61.60
85	0.40	0.0447	16.4	0.062	2.81	0.40	0.239	40.60
85	0.39	0.0378	14.6	0.060	2.89	0.38	0.218	43.54
85	0.37	0.0317	12.2	0.054	2.83	0.37	0.182	50.91
85	0.35	0.0224	10.9	0.062	3.18	0.30	0.175	50.36
70	0.40	0.0447	18.6	0.103	2.81	0.33	0.280	30.54
70	0.39	0.0378	16.6	0.095	2.89	0.31	0.253	34.36
70	0.37	0.0317	14.5	0.092	2.83	0.29	0.219	40.79
70	0.35	0.0224	12.5	0.086	3.18	0.24	0.198	43.67

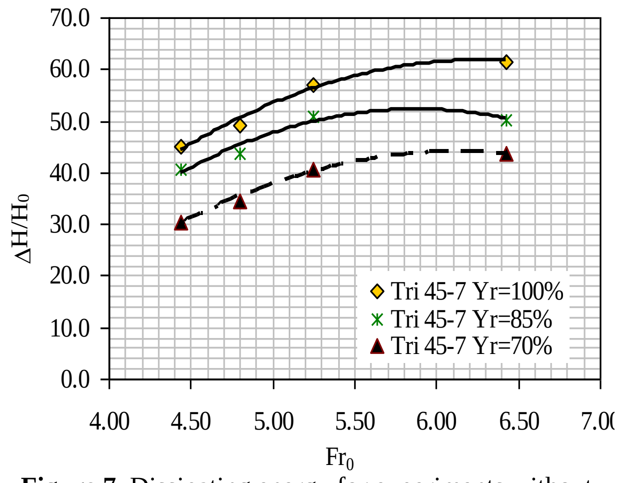

Figure 7. Dissipating energy for experiments without deflector in different tail water depths

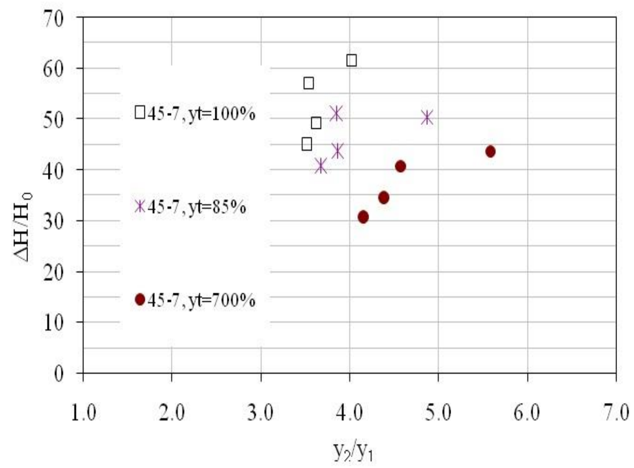

Figure 8. Dissipating energy for experiments without deflector indifferent tail water depths in relative hydraulic jump depth

Figure 9 to 11 have shown energy dissipation in 3 cases 100%, 85%,70% for 3 deflector with 6 , 9 and12 cm length and 25 degree angle. The maximum amount of energy dissipation is 70.3% which has occurred in 6.7 Froude number. Energy dissipation for the length sides of 12 cm for the Froude number 6.5 had the highest amount of energy dissipation.

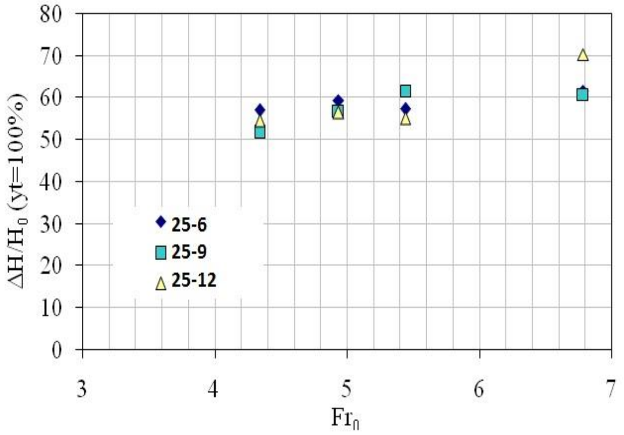

Figure 9. Dissipating energy for experiments with deflector 100% tail water

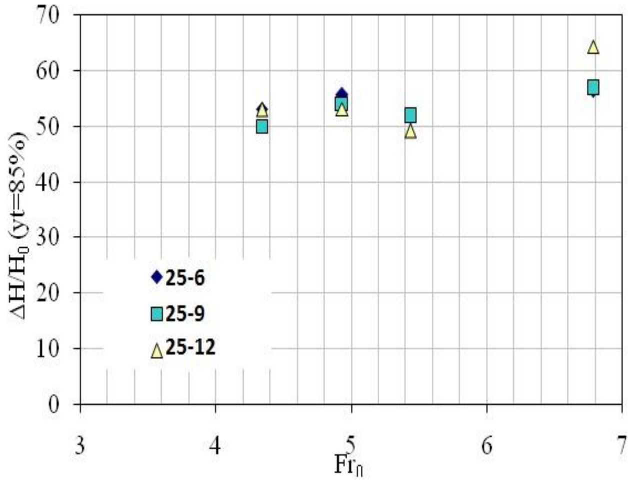

Figure 10. Dissipating energy for experiments with deflector 85% tail water

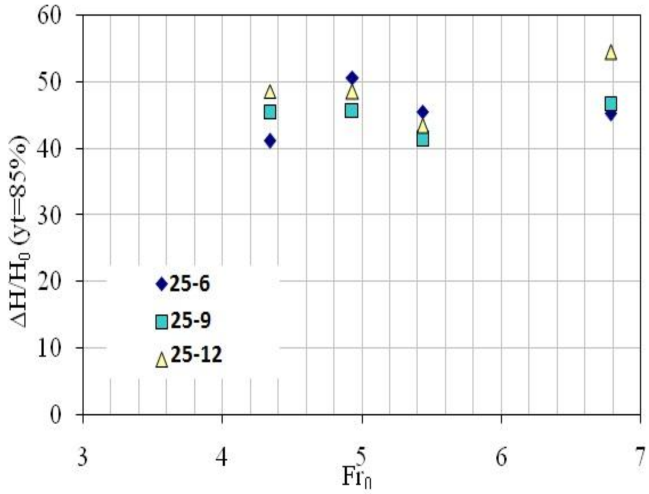

Figure 11. Dissipating energy for experiments with deflector 70% tail water

Figure 12 shows the relationship between dissipating energy and relative depths of hydraulic jump. As it shown increasing the y2/y1 would result to decrease the amount of the energy dissipation, so by increasing the tail water depth dissipating energy would decrease.

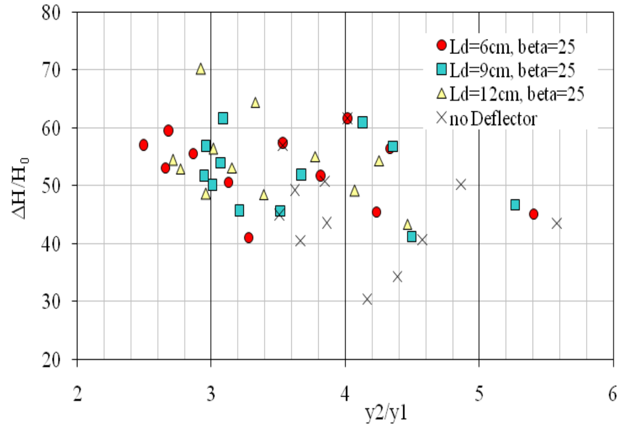

Figure 12. Dissipating energy for experiments with deflector indifferent tail water depths in relative hydraulic jump depth

CONCLUSIONS

Flip buckets with a deflector have received minor attention, although thousands of those structures exist worldwide. In the present study several scenarios have been assumed to employ deflector in the flip bucket spillway with approach channel.

On average the deflector angle, θ=25°, L=12 cm had the peak amount of energy dissipation which is 70.3%.

Energy dissipation will increased by increasing the Froude number for the bucket without and without deflector.

Dissipating energy in 100% tail water is maximum and in 70% tail water is minimum.

By increasing the tail water depth dissipating energy would decrease.

So, Deflector plays significant role in formation of flow dispersion in the air and as result more energy dissipation.

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