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EXPERIMENTAL RESULTS OF SKI-JUMP BASED ON DEFLECTORS

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ABSTRACT
This paper presents the experimental results of the trajectory flow from deflectors ski-jump bucket. For laboratory study, a 1:100 scale model was designed. The experiments were carried out by placing a model in hydraulic flume. Besides, this paper also draws a comparison of experimental results between conventional ski-jump bucket (CSB) and deflectors ski-jump bucket (DSB). Experimental results showed that energy dissipation of deflectors ski-jump bucket (DSB) was found to be higher
Keywords: **Spillway, Ski-jump bucket, Deflector, Trajectory, Model.**

1. Introduction

Dams were built taller and wider with the advancement of technologies and therefore new problems such as energy dissipation and scour arose. Since for taller dam energy dissipator such as hydraulic jump type, impact type and roller bucket type are not suitable. One of the most effective and economical methods for the dissipation of energy from taller dam is Ski-jump bucket type energy dissipator. Ski-jump bucket energy dissipator was introduced in France on Dordogne hydraulic scheme in the mid of 1930s. Ski-jump bucket energy dissipator become popular for large dams in recent years due to its ability to safely convey high velocity flow in excess of 20 m/s to the downstream plunge pool. An exhaustive experimental study was done on conventional ski-jump bucket energy dissipator by various researchers are given below:

Mazumder et al. [1] tested a model made up with 1:100 scale of ski- jump energy dissipator to find the applicability of the various formulas given in IS 7365(1985). The objective of their study was to compare experimental results with result obtained by formula given in IS code. In general, it has been concluded that experimental result for horizontal throw, throw height and energy dissipation were found to be higher than one found by formula given in the IS 7365 (1985). The energy dissipation was found to vary from 26% to 54.4%.

Heller and Hager [2] presented in their paper the experimental results of the ski-jump bucket by varying bucket radius and deflection angle. In general, it has been concluded that the energy dissipation across a ski-jump was increases with drop height. The energy dissipation rate of 40% was attained.

Schmocker et al. [3] analyzed jet air entrainment for a circular Ski-jump bucket of radius 0.40 m and take off angle 30^o

Pfister et al. [4] studied four aspects of ski-jump bucket: Geometry of upper and lower jet trajectories, Virtual jet take-off angles for the trajectory computations and Average and minimum cross-sectional air concentrations.

After reviewing the literature, it was found that the energy dissipation for conventional ski-jump bucket was about 26% to 54.4% as per Mazumder et al. [1] and 40% as per Heller and Hager [2]. A research work was carried out to increase energy dissipation by fixing triangular shape deflector on one side of ski- bucket by Juon and Hager [5] and by Lucas et al [6]. They conducted test to find energy dissipation by using deflector. The energy dissipation was found to vary between 40 % to 70%.The studies by fixing deflectors on both side of ski-jump bucket were not done by any researcher. Deflectors have been proposed in the past [e.g., Gong et al. (1987) for the flaring gate pier and Zhenlin et al. (1988) for the slit-type flip-bucket]. Deflector is sometimes provided to deflect jet from the bucket toward the main river when the spillway is located on the flank. Deflectors are the element provided at the outlet to deflect the trajectory into an area of plunge pool where sound rock is present so that erosion will be less. Deflectors are also used: to enhance jet dispersion, to spread and to elongate the jet trajectory.

2. hydraulic model

For experimental study, a model of gated ogee spillway with the conventional ski-jump bucket (CSB) energy dissipator was designed with a scale of 1:100. The selected scale was suitable for hydraulic flume and similarity condition. The prototype spillway data used for design was: Design discharge (Q_d)-946.90 m3/s, length of spillway (L)-30 m and height of spillway (h)-21.2 m. The various design parameters and photo of (CSB) model are shown in Figure 1.

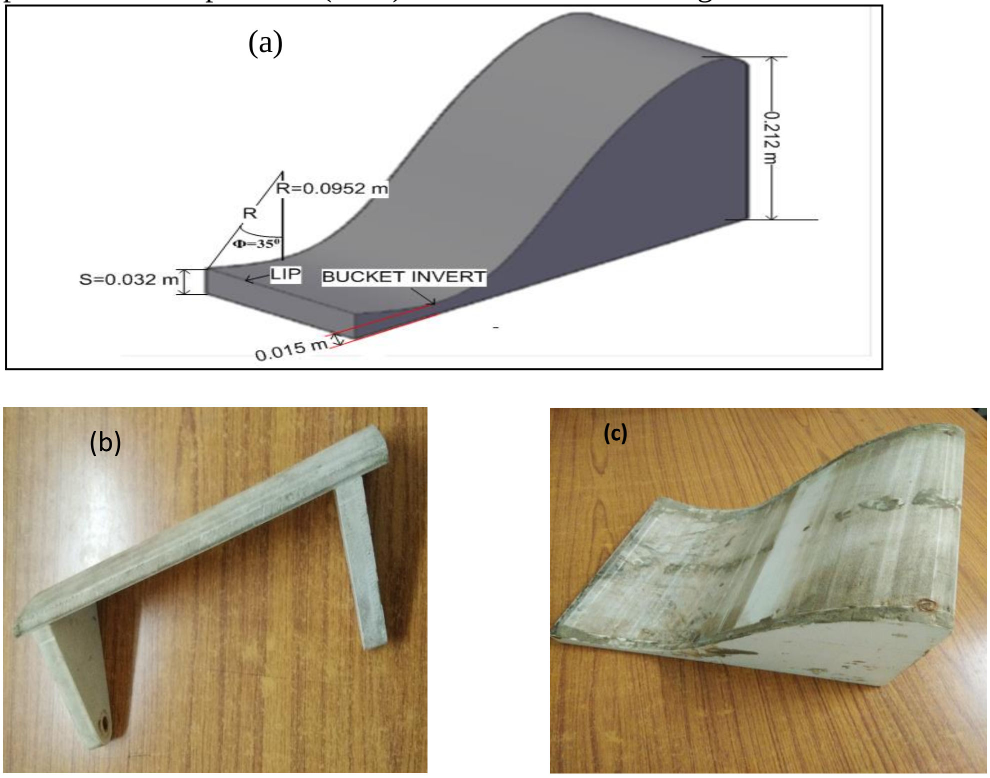

Figure 1: (a) Design parameters for CSB model (with Notation as: R - Radius of bucket, Φ-Lip angle, S-Height of lip) (b) Photo of fabricated CSB model and (c) Photo of fabricated radial gate (Radius - 0.0913 m).

3. Characteristics of used deflectors

During the experiment work, the operation of two types of ski-jump bucket was tested:

• Conventional type of ski-jump bucket (CSB) and
• Deflectors ski-jump bucket (DSB)

For the present work deflectors made up of the simple triangular shape with vertical sidewalls were selected. Selection of geometric design of deflector and shape was based on the previous research by Juon and Hager [6]. The deflector was characterized by the length-(a) along the direction of flow, width-(b) in transverse direction of flow and height-(c).

The graphical representations of geometric design parameter of deflectors were shown in Table 1 and Figure 2 (a). Photo of fabricated deflectors were shown in Figure 2(b).

Table 1 :Geometric design parameters of the deflectors

Shape	**Length (a) (m)**	**Width (b) (m)**	**Height (c) (m)**
Triangular	0.10	0.06m	0.03m

(a)

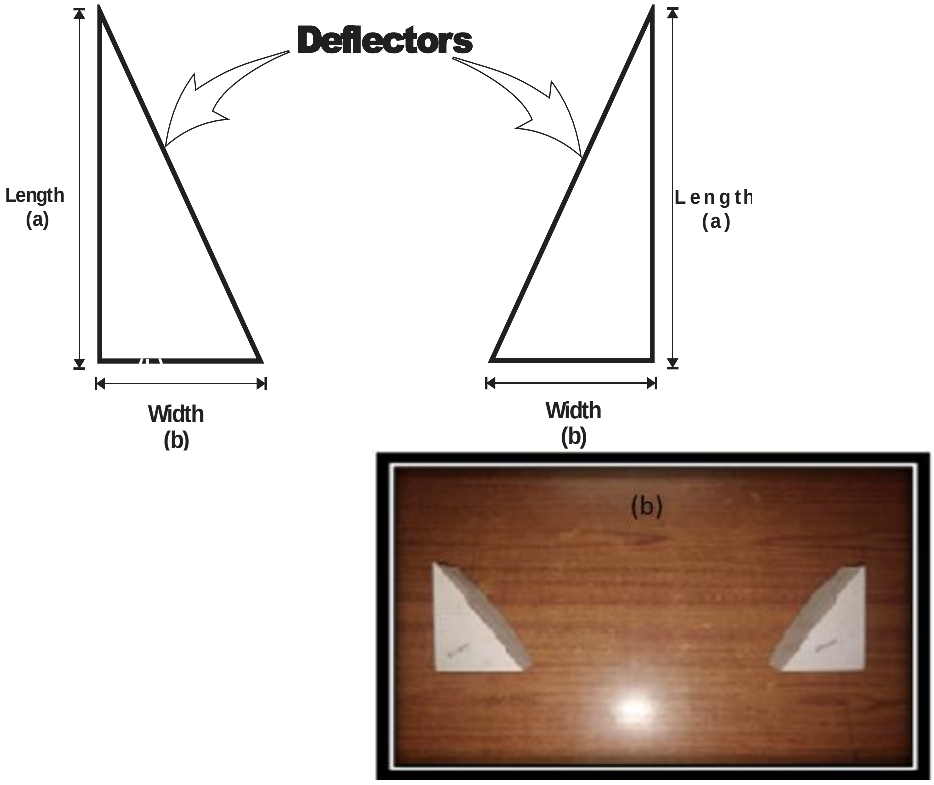

Figure 2: (a) Graphical representation of design parameters of deflectors (b) Photo of fabricated Deflectors

4. Experimental methodology and measurements

For experimentation the model was placed in center of hydraulic flume. Figure 7 shows side view of model installed in flume.

Hydraulic Flume details:

- Tilting flume in the form of rectangular channel with test section portion which has acrylic side walls.
- Length of flume (L) = 6 m
- Width of flume (B) = 0.30 m
- Height of flume (H) = 0.30 m
- Maximum discharge (Q_{max}) = 0.00962 m^3/s `
- Slope = horizontal

Experimental conditions:

- Range of discharge = 0.00962m^3/s (Q_{max}) to 0.00255 m^3/s (Q_{min}).
- Tail water level (TWL) = Normal water level (NWL) corresponding to given discharge.

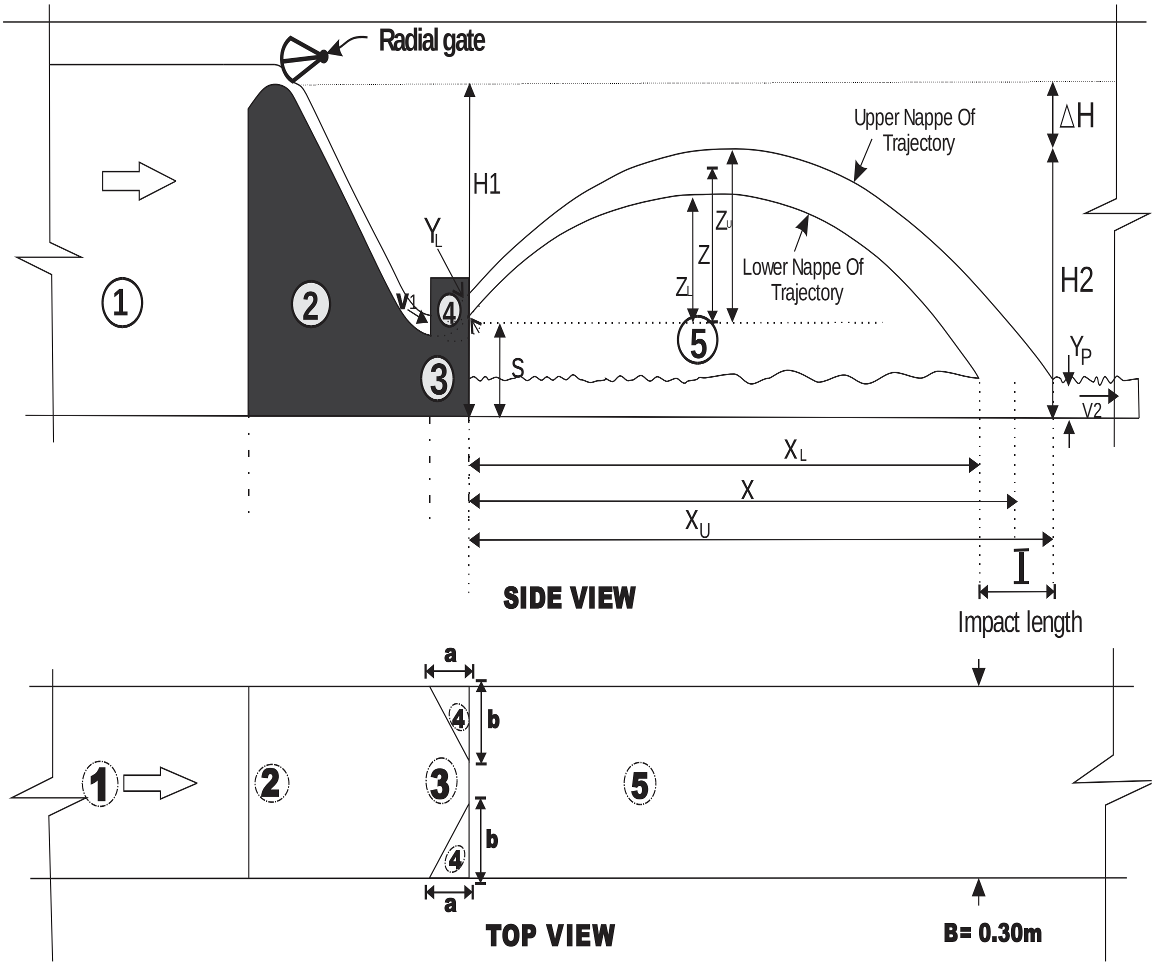

Figure 3, Ski-jump bucket parameters measured and Schematic view of deflector setup in flume (with Notation as: 1 Upstream of hydraulic model in flume, 2 Ogee spillway, 3 Ski-jump bucket, 4 Deflector, 5 Downstream of hydraulic model in flume).

The experiments were performed for ten different discharges. The experimental work includes measurements of: Characteristics of trajectory and Energy dissipation. Characteristics of trajectory measured include trajectory length (X) and trajectory height (Z). Trajectory length was the horizontal distance of trajectory measured from bucket lip to the point of impact in tail water. Trajectory height was the vertical distance of trajectory measured above bucket lip.

The energy dissipation across the ski-jump can be defied as:

$\eta = H_1 - H_2$

$\eta = (S + Y_L + V_1^2/2g) - (Y_P + V_2^2/2g)$

Where-

H_1 = Energy head on lip
H_2 = Energy head in tail water
Y_L = Depth of flow on lip
Y_P = Depth of flow in tail channel
V_1 = Velocity of flow on lip
V_2 = Velocity of flow in tail channel
S = Lip height

The details of experimental setup and schematic view of deflector setup were shown in figure 3. Deflectors were fixed along the sides of the ski-jump bucket. Figure 8 shows view of deflectors installed on conventional ski-jump bucket (DSB).

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5. Discussions of results

The hydraulic performance of Conventional type of ski-jump bucket (CSB) and Deflectors ski-jump bucket (DSB) was done for 10 discharges. As per the visual observation it was found that, clear Ski-jumps were formed for all range of discharges for both type of bucket. Figure 4 shows the comparison of trajectory length and Figure 5 shows comparison of trajectory height. The trajectory length and trajectory height for Deflectors ski-jump bucket (DSB) were found to be higher than Conventional type of ski-jump bucket (CSB). Figure 6 shows the comparison of energy dissipation. The energy dissipation for conventional ski-jump bucket (CSB) were found to vary between 46.87% to 56.98%.The energy dissipation for Deflectors ski-jump bucket (DSB) were found to vary between 71.78% to 70.2%. For all flow conditions the energy dissipation for Deflectors ski-jump bucket (DSB) were found to be higher than Conventional type of ski-jump bucket (CSB).Table 2 and Table 3 gives summary of experimental results. Figure 7 and Figure 8 shows photo during experiment.

Table 2. Summary of experimental results for CSB

Q (m^3/s)	**Y_L (m)**	**V_L (m/s)**	**Y_P (m)**	**V_L (m/s)**	**η (%)**
0.00962	0.016	2.004	0.0223	1.437	49.60
0.00735	0.012	2.042	0.0159	1.54	47.16
0.00595	0.01	1.983	0.0143	1.386	52.04
0.00500	0.0082	2.032	0.0114	1.461	51.00
0.00431	0.0072	2.052	0.0099	1.451	53.93
0.00379	0.006	2.105	0.0087	1.452	55.89
0.00338	0.0057	1.976	0.0082	1.37	55.50
0.00305	0.0051	2.00	0.0074	1.373	56.66
0.00278	0.0046	2.014	0.0066	1.404	56.32
0.00255	0.0041	2.073	0.0058	1.465	54.29

Table 3.: Summary of experimental results for DSB

Q (m^3/s)	**Y_L (m)**	**V_1 (m/s)**	**Y_P (m)**	**V_2 (m/s)**	**η (%)**
0.00962	0.0265	2.016	0.0375	0.855	71.78
0.00735	0.02	2.041	0.0244	1.004	71.27
0.00595	0.0162	2.040	0.0192	1.066	71.8
0.00500	0.0135	2.058	0.015	1.096	70.3
0.00431	0.0114	2.100	0.0123	1.168	69.42
0.00379	0.0101	2.085	0.0101	1.226	68.05
0.00338	0.009	2.087	0.0094	1.198	68.01
0.00305	0.0081	2.091	0.0087	1.168	70.04
0.00278	0.0074	2.087	0.0076	1.219	67.78
0.00255	0.0068	2.083	0.0072	1.180	70.2

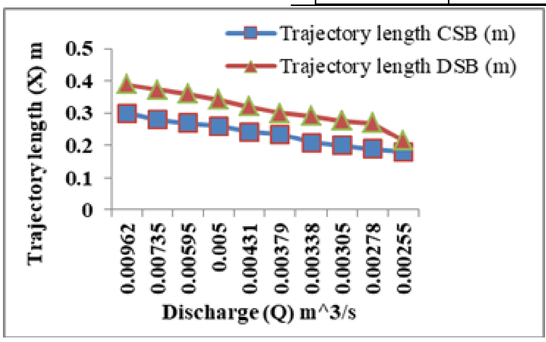

Figure 4: Plot of Q Vs. X for conventional ski-jump bucket (CSB) and Deflectors ski-jump bucket (DSB).

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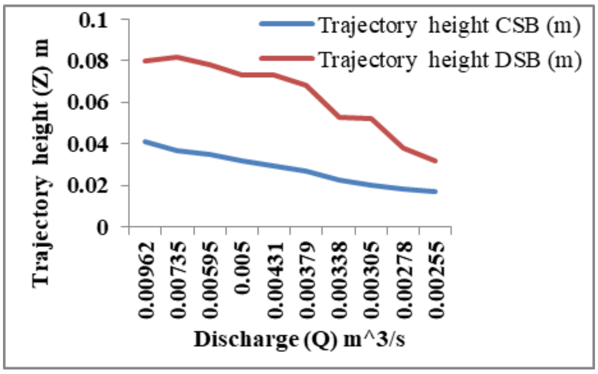

Figure 5, Plot of Q Vs. Z for conventional ski-jump bucket (CSB) and Deflectors ski-jump bucket (DSB).

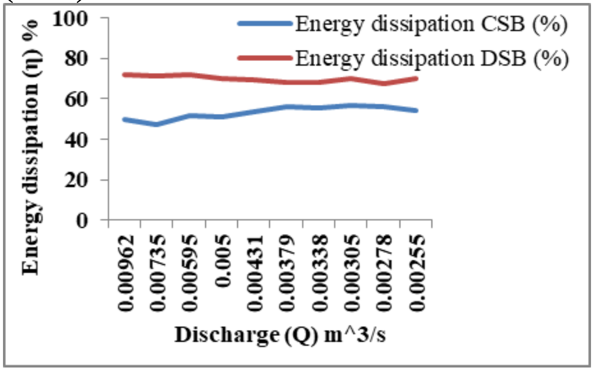

Figure 6, Plot of Q Vs. η for conventional ski-jump bucket (CSB) and Deflectors ski-jump bucket (DSB).

Figure 7: Side view of CSB model installed in flume.

Figure 8: Side view of DSB model installed in flume.

Comparing results of present study with literature

- The energy dissipation of present study for conventional ski-jump bucket (CSB) were found to vary between 46.87% to 56.98%, which was slightly higher than energy dissipation prescribed by Mazumder et al. [1]. The errors may be due to fact that, In Mazumder study model bed was made up with sand.

- The energy dissipation of present study for deflectors ski-jump bucket (DSB) were found to vary between 71.78% to 70.2%, which was slightly higher than energy dissipation prescribed by Lucas et al. The errors may be due to fact that, Lucas study was done by fixing deflector only on one side of bucket, whereas in present study deflectors were fixed on both side of bucket.

6. CONCLUSIONS

In this research, a 1:100 scale model of a conventional ski-jump bucket (CSB) and Deflectors ski-jump bucket (DSB) were tested. When comparing results, it was evident that Deflectors ski-jump bucket (DSB) yielded the best results with regard to the energy dissipation. The conclusions drawn are as follows:

- The values of trajectory length and trajectory height for Deflectors ski-jump bucket (DSB) were found to be higher than conventional ski-jump bucket (CSB).
- The energy dissipation for ski-jump bucket with deflector was found higher than conventional ski-jump bucket (CSB).

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