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HYDRAULIC MODEL STUDY OF SKI-JUMP BUCKET ENERGY DISSIPATOR WITH AND WITHOUT DEFLECTOR

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Abstract:
On spillway, ski-jump bucket energy dissipator is provided when take-off velocity exceeds 20 m/s. The aim of present study was to investigate characteristics of trajectory and energy dissipation in ski-jump bucket energy dissipator with and without deflectors. Deflector is a small element, sometimes provided to deflect the trajectory from the ski-jump bucket toward the main river when the spillway is located on the flank. For laboratory study a 1:100 scale model of ski-jump bucket energy dissipator was designed and fabricated. Triangular shaped deflectors were designed and fabricated with same scale. For experimentation deflectors were fixed along the sides of the ski-jump bucket. For present study, experiments were conducted in a laboratory flume of size 6.00m length, 300mm width and 300mm depth. The maximum discharge capacity of the flume was 10 lit/s. In the present study characteristics of trajectory and energy dissipation with deflectors on ski-jump bucket were measured and results were compared with conventional ski-jump bucket energy dissipator without deflector. This paper intends to provide a new approach for improving energy dissipation by using deflectors for ski-jump bucket energy dissipator. The result indicates that the deflectors have significant effect on characteristics of trajectory and energy dissipation. The result shown that the uses of deflectors on ski-jump bucket improve energy dissipation.
Keywords: Ski-jump bucket, Deflector, Trajectory, Lip, Plunge pool.

I. INTRODUCTION

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 20m/s to the downstream plunge pool. In the Ski-jump bucket energy dissipator flow is discharge in the form of trajectory away from the hydraulic structure into a plunge pool. Trajectory bucket, flip bucket, free jet spillways and free over-falls are the different names of Ski-jump bucket energy dissipator in different country. Ski-jump bucket energy dissipator structures consist of three main sections: 1. Ski-jump bucket, 2. Ski-jump/Trajectory and 3. Plunge pool. Fig.1shows three main sections of ski-jump bucket energy dissipator. Ski-jump bucket dissipates energy with the effects of air resistance and air entrainment in combination with impact diffusion in plunge pool.

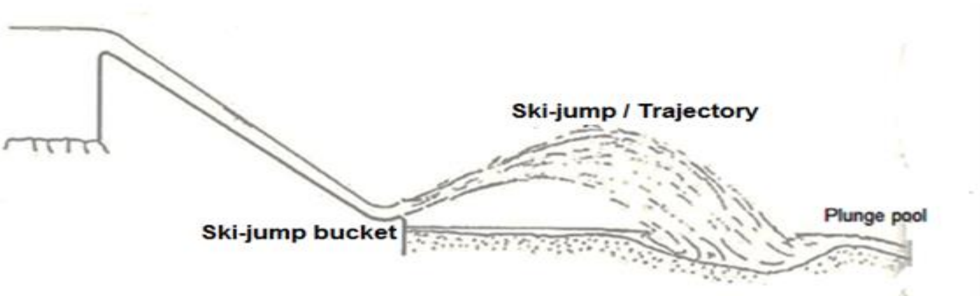

Figure.1. Ski-jump bucket energy dissipator

Ski-jump bucket energy dissipator was introduced in France on Dordogne hydraulic scheme in the mid of 1930s. The experiments with ski-jump bucket for hydraulic performance by varying bucket radius and deflection angle have been conducted by Heller et al. (2005), the experimental results shown that the energy dissipation across a ski-jump was increases with drop height and the energy dissipation rate of 40% was attained.

Mujumdar et al. (2001) tested a model made up with 1:100 scale of ski- jump energy dissipator to find the applicability of the design guideline given in IS 7365(1985), results shown that energy dissipation due to air entrainment and by impact was found to be varying from 26% to 54.4%.

Schmucker et al. (2008) analysed jet air entrainment with a circular Ski-jump bucket of radius 0.40m and take off angle 30o, they had used twin fiber optical probe for jet air concentration measurement.

A new type of bucket called as triangular-shaped bucket was introduced by Steiner et al. (2008), a study was carried out to compare the hydraulic performance of a triangular-shaped bucket with circular shape bucket. The result had shown relatively small difference in hydraulic performance with circular and triangular bucket except for the pressure head distribution.

The effects of take-off velocity on characteristics of trajectory for a triangular-shaped flip bucket have been studied by Jian-hua et al. (2016).

Pfister et al. (2014) studied four aspects of ski jump:

- Geometry of upper and lower jet trajectories
- Virtual jet take-off angles for the trajectory computations
- Average and minimum cross-sectional air concentrations along the jet and
- General jet air concentration profiles.

Ramarao et al. (2016) and Sundarlal et al. (2016) carried out scour studies for ski-jump bucket energy dissipator to know the extent and depth of the deepest scour downstream of the ski-jump bucket in order to finalize the design of pre-formed plunge pool.

Juon et al. (2000) and Lucas et al. (2013) focused on the use of a deflector for ski-jump bucket. They conducted tests to find simple-shaped deflector, bottom pressure distribution and characteristics of lower and upper trajectory. The results shown that deflector geometry affects the jet shape and energy dissipation.An attempt was made to increase energy dissipation and unit discharge on stepped chute by Qian et al. (2016). They introduced a new type of energy dissipater called a ski-jump-step energy dissipator, the new type of energy dissipator consist of two stages, each stage includes a ski-jump, a prestep, an aeration basin and a stepped chute. Results had shown that, unit discharge limitation on stepped chute increases to 118 m2/s and also the energy dissipation increases as high as 75.8%.

II.HYDRAULIC MODEL AND DEFLECTOR

Hydraulic model of ogee spillway with the ski-jump bucket energy dissipater was designed with a scale of 1:100. The selected scale is suitable for hydraulic flume available in laboratory. The prototype spillway data taken for design is given in Table 1.

Table 1: Prototype spillway Design data

Design discharge:	946.90 m3/s
Width of spillway:	30m
Height of spillway:	21.2m
D/S slope:	0.7(H):1(V)

The Froude number and similarity between prototype and model are assumed to be equivalent i.e. $Frprototype = Frmodel$. The scale relationship obtained as shown in Table 1 is valid for the model and prototype (model representation is denoted by suffix ‘m’ and prototype by suffix ‘p).

Table 2: Scale relationship for model

Froude number ratio:	$Frp/Frm = 1$
Linear ratio:	$LP/Lm = \lambda = 100$

Area ratio:	$LP2 /Lm2= \lambda 2 = 10000$
Volume ratio:	$LP3/Lm3= \lambda 3 = 1000000$
Velocity ratio:	$Vp /Vm= \lambda o.5 = 10$
Discharge ratio:	$VpVm$ x $LP2\ Lm2 = \lambda 2.5 =$ 100000

From the prototype spillway design data and selected scale different parameters for spillway model are calculated which are shown in Table 3.

Table 3: Parameters for spillway model

Discharge:	0.0946 m3/s
Head	0.059m
Width of spillway:	0.30m
Height of spillway:	0.212m
D/S slope:	0.7(H):1(V)

The principal features of hydraulic design of Ski-jump bucket consist of determining: Bucket invert elevation, Radius of bucket, Lip elevation and lip angle. The ski-jump bucket was designed as per IS 7365 (2010). The principal features of Ski-jump bucket model designed are shown in Table 4.

Table 4: Features of Ski-jump bucket model

Bucket invert elevation	0.015m
Radius of bucket	0.095m
Lip elevation	0.032m
Lip angle	350

In present study a triangular shaped deflectors were designed and fabricated. The deflector are characterised by the length-(a) along the direction of flow, width-(b) in transverse direction of flow and height-(c). The characteristics of deflector used for model study is shown in Table 5 and Figure 2.

Table 5: Charactristics of deflector for model

Type	Length (a)	Width (b)	Height (c)
I	0.132m	0.06m	0.03m

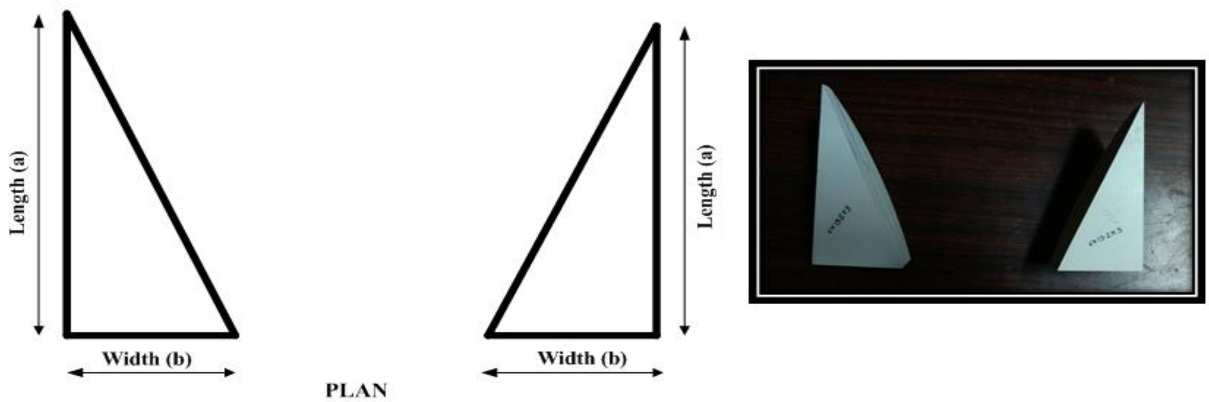

Figure.2. Type I deflector

III.METHODOLOGY

The experiments were conducted in a laboratory flume of size 6.00m length, 300mm width and 300mm depth. For experimentation model were fixed in the centre of the flume as shown in figure 3.In the present study initially, experiments were conducted with conventional ski-jump bucket energy dissipator without deflectorand then finally deflectors Type I, were fixed along the sides of the ski-jump bucket and experimentation were completed. The deflector setup is shown in figure 4 (a) and figure 4 (b).

Figure.3. Conventional ski-jump bucket

The experiments were performed for ten different flow conditions shown in Table 6 and Table 7. The discharge over the spillway was controlled by radial gate.The various hydraulic parameters tested includes: (1) Characteristics of trajectory (Trajectory length and vertical distance of trajectory above lip) and (2) Energy dissipation across a ski-jump. Trajectory length is defined as throw distance from bucket lip to the centre point of impact in tail water (measured by scale).Vertical distance of trajectory above lipis defined as a distance of trajectory from the lip level to the highest point of the centre of trajectory (measured by scale). The energy dissipation across the ski-jump can be defied as $\eta=\Delta H/H_1$, where $\Delta H=H_1-H_2$, $H_1=h_1+v_1^2/(2g)$ is the energy head on lip of bucket and $H_2=h_2+v_2^2/(2g)$ is the energy head in tail water channel. Here h_1 and h_2 were the flow depth on lip and in tail water respectively, v_1 and v_2 were corresponding mean velocities calculated by dividing discharge by the flow area.

Figure.4 (a). Plan view 1 Ogee spillway. 2 Ski-jump buckets. 3 Plunge pool

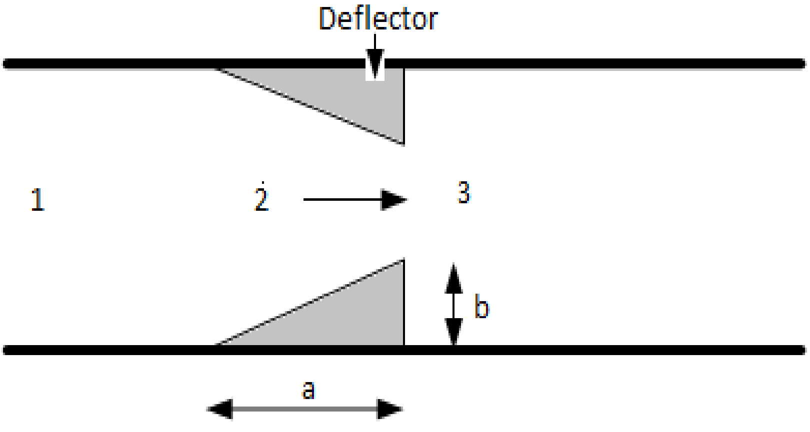

Figure. 4 (b). Plan view of deflectors setup

IV.Results and Discussions

Table 6 shows experimental results for conventional ski-jump bucket energy dissipator without deflector. The experiments were performed for ten different approach flow conditions. The approach flow condition was varied between 0.00962 m^3/s to 0.00278 m^3/s. Characteristics of trajectory measured includes trajectory length and vertical distance of trajectory above lip. Trajectory length is the distance measured from the bucket lip to centre point of impact. The vertical distance of trajectory is the distance from the lip level to the highest point of the centre of trajectory.

The measured trajectory length and vertical distance of trajectory were found to be decrease with decrease in discharge. The highest value of Trajectory length and vertical distance of trajectory occurs for flow condition -1 i.e. for discharge 0.00962 m3/s. Energy losses were found after working out energy level at lip and energy level after the point of impact of trajectory in plunge pool. The total energy loss is found to be varying from 46.87% to56.98%. It may again find that highest energy loss occurs for flow condition-9 i.e. for discharge 0.00278 m3/s. The downstream view of conventional ski-jump bucket is shown in figure 5.

Table 6: Results forConventional ski-jump bucket .

Flow Condition	Discharge Q (m^3/s)	Trajectory Length X_c (m)	Trajectory Height Z_c (m)	Energy Dissipation η_c (%)
1	0.00962	0.3	0.07	49.55
2	0.00735	0.28	0.037	46.87
3	0.00595	0.27	0.074	53.63
4	0.00500	0.26	0.043	52.49
5	0.00431	0.245	0.045	53.73
6	0.00379	0.235	0.032	55.98
7	0.00338	0.21	0.032	55.53
8	0.00305	0.2	0.039	56.98
9	0.00278	0.19	0.032	56.93
10	0.00255	0.18	0.26	54.90

Figure.5. Downstream view of Conventional ski-jump bucket energy dissipator

Table 7 shows experimental results for ski-jump bucket with Type I deflector.The measured trajectory length and vertical distance of trajectory were found to be decrease with decrease in discharge. The highest value of Trajectory length and vertical distance of trajectory occurs for flow condition -1 i.e. for discharge 0.00962 m3/s. Energy losses were found after working out energy level at lip and energy level after the point of impact of trajectory in plunge pool. The total energy loss is found to be varying from 67.43% to72.47%. It may again find that highest energy loss occurs for flow condition-2 i.e. for discharge 0.00735 m^3/s. The downstream view of ski-jump bucket with deflector is shown in figure 6.

Table 7: Results forski-jump bucket with Type I deflector

Flow Condition	Discharge Q (m^3/s)	Trajectory Length X_d (m)	Trajectory Height Z_d (m)	Energy Dissipation η_d (%)
1	0.00962	0.36	0.115	70.35
2	0.00735	0.32	0.037	72.47
3	0.00595	0.31	0.102	71.78
4	0.00500	0.26	0.043	70.81
5	0.00431	0.24	0.045	69.05
6	0.00379	0.23	0.085	67.43
7	0.00338	0.21	0.032	68.01
8	0.00305	0.22	0.039	69.01
9	0.00278	0.22	0.032	67.78
10	0.00255	0.21	0.071	72.10

Figure.6. Downstream view of ski-jump bucket energy dissipator with Type I deflector

The figure 7 shows the comparison of trajectory length for ski-jump bucket with and without deflectors. The values of trajectory length for ski-jump bucket with deflector are found to be higher than ski-jump bucket without deflector for flow condition 1, 2, 3, 8, 9 and 10. The values of trajectory length for ski-jump bucket with and without deflector are found to be equal for flow condition 4 and 7. The values of trajectory length for ski-jump bucket with deflector are found to be lower than ski-jump bucket without deflector for flow condition 5 and 6.

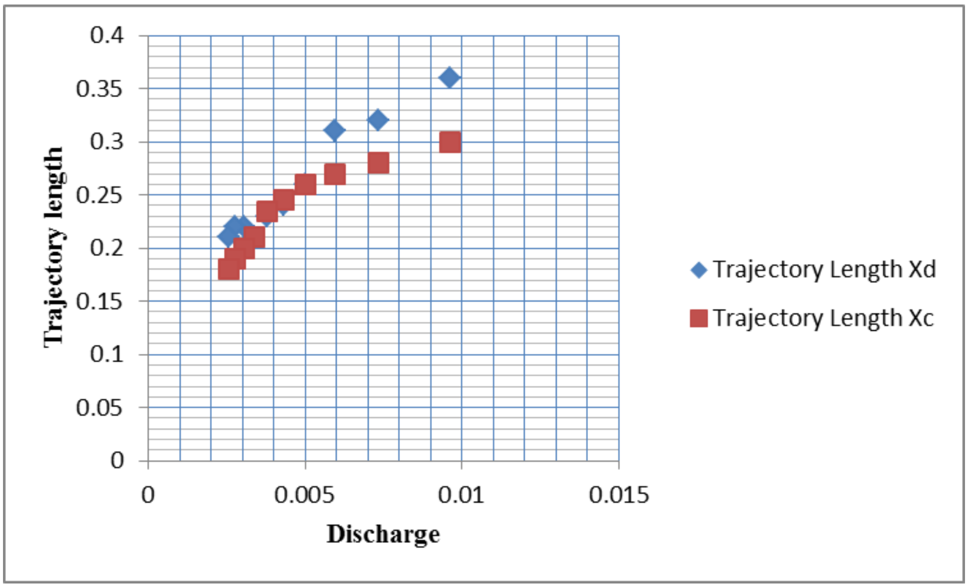

Figure.7. Comparison of trajectory length with and without deflector

The figure 8 shows the comparison of trajectory height for ski-jump bucket with and without deflectors. The values of trajectory height for ski-jump bucket with deflector are found to be higher than ski-jump bucket without deflector for flow condition 1, 3, 5, 6, 7, 8, 9 and 10. The values of trajectory height for ski-jump bucket with and without deflector are found to be equal for flow condition 4. The values of trajectory height for ski-jump bucket with deflector are found to be lower than ski-jump bucket without deflector for flow condition 2.

The figure 9 shows the comparison of energy dissipation for ski-jump bucket with and without deflectors. The values of energy dissipation for ski-jump bucket with deflector are found to be higher than ski-jump bucket without deflector for all flow conditions.

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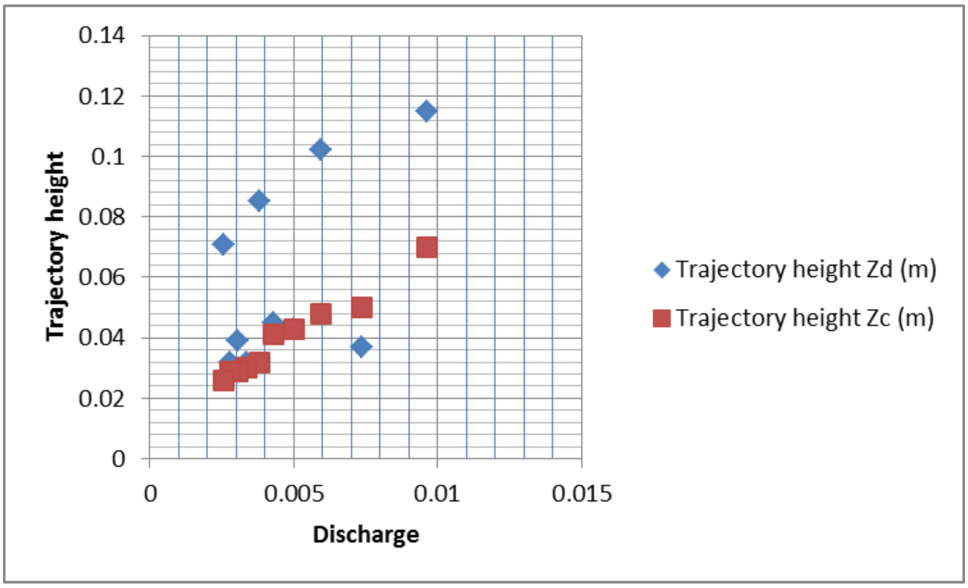

Figure.8. Comparison of trajectory height with and without deflector

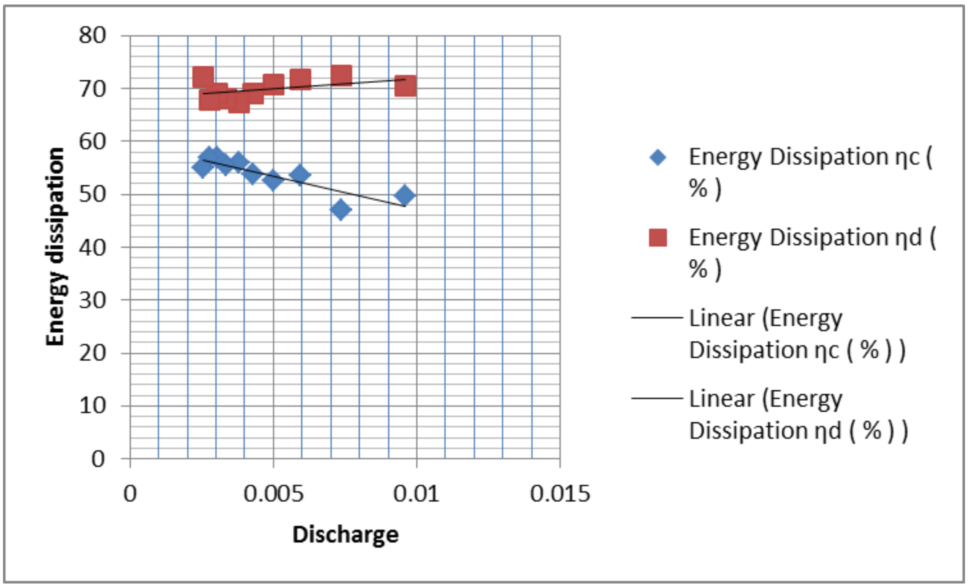

Figure.9. Comparison of energy dissipation with and without deflector

V. CONCLUSIONS

In this research 1:100 scale model of a ski-jump bucket energy dissipator with and without deflector were tested. Ten flow conditions were analysed to determine characteristics of trajectory and energy dissipation. When comparing results of ski-jump bucket energy dissipator with and without deflector it is evident that ski-jump bucket with deflectors yielded the best results with regard to the energy dissipation. The conclusions drawn are as follows:

- The values of trajectory length for ski-jump bucket with deflectors are found to be higher than ski-jump bucket without deflectors for flow condition 1, 2, 3, 8, 9 and 10.
- The more trajectory length effect in minimizing scouring near bucket.
- The values of throw height for ski-jump bucket with deflectors are found higher than ski-jump bucket without deflectors for flow condition 1, 3, 5, 6, 7, 8, 9 and 10.
- The more trajectory height enhances the air entrainment.
- The energy dissipation for ski-jump bucket with deflectors is found higher than ski-jump bucket without deflectors for all flow conditions.

- The total energy loss for ski-jump bucket without deflectors is found to be varying from 46.87% to56.98%.
- The total energy loss for ski-jump bucket with deflectors is found to be varying from varying from 67.43% to72.47%.
- A deflector is a small element; a significant advantage of deflector is the increase level of energy dissipation and this effect minimizing scouring on downstream of bucket.

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