Energy Dissipation in Solid Roller Bucket and Controlled Stilling Basin for Ogee Stepped Spillway

A. S. Kote, P. B. Nangare

***Abstract:** Hydraulic jump type II stilling basin is generally preferred as an energy dissipator for ogee spillway but it is uneconomical due to longer structure. On the other hand, roller bucket uses relatively shorter structure over a sloping apron or horizontal stilling basin. In this study, an attempt has been made to evaluate the performance of an ogee profile stepped spillway in combination with solid roller bucket and stilling basin type II for energy dissipation. Laboratory experiments are performed on a physical working model of ogee profile stepped spillway at discharge ranging from 0.0032 to 0.0069 m^3/s for a head of 1.5m, 4m & 7m and the results compared for energy dissipation (non-dimensional parameter (y_c / h) = 0.69). The model results show that stepped spillway model without v-notch achieves 92.40 % energy dissipation. Thus this model is found to be more suitable to acquire the ideal condition of sequent depth and tail water depth in stilling basin for all the discharges.*

***Keywords:** Energy dissipation, Controlled stilling basin, Non-dimensional parameter, Ogee stepped spillway, Solid roller bucket..*

I. INTRODUCTION

Terminal structure of an ogee spillway plays a vital role in dissipating specific energy of flood water so as to safe guard downstream structure of dam. Due to high discharge of excess floods there are chances of erosion of spillway bed. Therefore in all circumstances the energy dissipator must be adequate and efficient to dissipate the specific energy effectively. Different types of energy dissipators *namely* stilling basin, roller buckets and flip bucket are used in ogee spillway for minimizing its impact on the ogee structure. The provision of steps on ogee profile acts as roughness element to decrease flow acceleration and toe velocity [2]. The decrease in velocity and entrainment of air reduces cavitation in the spillway. Excess air entrainment causes positive pressure on spillway bed and is helpful to enhance energy dissipation [9].

However roller buckets requires unit discharge less than 50 $m^3/s/m$ to dissipate the specific energy effectively on ogee spillway chute [1]-[10].

Revised Manuscript Received on November 15, 2019

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Thus there is a broader scope to utilize combined effect of steps, solid roller bucket and hydraulic jump type of stilling basin on ogee spillway. Ogee spillway of Khadakwasla dam, Pune has stilling basin type of energy dissipator with friction blocks. The problems like scour, erosion, and formation of pot holes are reported by dam inspection authority, central design organization, Nashik (India). In this present study, an attempt has been made to develop a physical model of ogee stepped spillway with solid roller bucket and controlled end sill type stilling basin for Khadakwasla dam spillway, Pune (India).

II. METHODOLOGY

In this model the combination of hydraulic jump type II stilling basin and solid roller bucket is used as an energy dissipator for evaluating the performance of ogee stepped spillway. The performance of stilling basin is helpful in identifying the ideal condition of tail water depth (y_t) for different discharges and heads. Sequent depth ratio (y_2/y_1) and tail water depth ratio (y_t/y_2) is observed in the model for determining efficiency of the stilling basin. The tail water depth deficit in Khadakwasla dam spillway is needed to overcome with controlled stilling basin [11]. In this study a new methodology is proposed to modify the length of stilling basin with controlled end sill for both ogee and stepped spillway. The ogee spillway is designed as per IS 6934 and roller bucket is designed as per IS 7365, 2010 [5]-[6]. The working model of ogee stepped spillway is developed on the basis of Froude model law with a model scale ratio of 1:33. The conditions assumed in the model development are i) The operational head of water over the crest of ogee spillway is less than 1.4 times design head ii) The solid roller bucket is kept under submergence with tail water in the range y_t = 1.1 to 1.4* y_2 ii) Fr_1> 4.5 for solid roller bucket and iv) Non-dimensional parameter defined as the ratio of critical depth (y_c) to step height (h) for stepped spillway, y_c /h < 0.8 [3]-[4]-[7].

The experiments are performed in a 6 m long, 300 mm wide and 300 mm deep tilting hydraulic flume for discharge ranging from 0.003 to 0.007 m^3/s. Steps are provided on ogee spillway chute with a slope of 0.75:1. Number of steps = 9 with a rise = 4.5 cm, tread = 5.0 cm and rise to tread ratio = 0.9 is used for stepped spillway. The performance of stilling basin is tested under the operational head of 1.5 m, 4 m and 7 m. The y_t is controlled in stilling basin by the provision of v-notch on end sill.

Experiments are performed with and without v-notch under different tail water conditions for ogee and stepped spillway. Fifteen models are studied to check the performance of

Retrieval Number: D7682118419/2019©BEIESP
DOI:10.35940/ijrte.D7682.118419

Published By:
Blue Eyes Intelligence Engineering
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stilling basin for specific energy (E), energy loss (ΔE), energy dissipation ($\Delta E/E_1$) and comparison of y_t with y_2. The models are designated as A_1, A_2, A_3, B_1, B_2, B_3, C_1, C_2, C_3, D_1, D_2, D_3, E_1, E_2 and E_3 for the three operational heads. The detailed description of models is as shown in Table I.

Table- I: Description of Models Based on Tail Water Depth Control using v-notch

Models	Type of Spillway	Operational Head (m)	Discharge (m^3/s)	Tail Water Depth (m)
A_1	Ogee Spillway (without v-Notch)	1.5	0.0032	-
A_2		4.0	0.0052	
A_3		7.0	0.069	
B_1	Ogee Spillway (with v-Notch)	1.5	0.0022	0.10
B_2			0.0027	0.14
B_3			0.0027	0.17
C_1	Ogee Spillway (with v-Notch)	4.0	0.019	0.10
C_2			0.0029	0.14
C_3			0.0034	0.17
D_1	Ogee spillway (with v-Notch)	7.0	0.0014	0.10
D_2			0.0025	0.14
D_3			0.0029	0.17
E_1	Stepped spillway (without v-Notch)	1.5	0.0032	0.003
E_2		4.0	0.0052	0.005
E_3		7.0	0.0069	0.007

III. RESULTS AND DISCUSSIONS

Experiments are performed on stepped spillway with controlled sill type stilling basin for different heads by controlling hydraulic jump in stilling basin with v-notch on end sill. The specific energy and energy dissipation over a ogee and stepped spillway with solid roller bucket and stilling basin for 15 models are compared with following observation at head of 1.5 m, 4 m and 7 m head. The results are compared for Froude number and energy dissipation as shown in Table II. The experimental result shows that the energy dissipation increases with increase in length of steps and achieves maximum energy dissipation with lowest value of non-dimensional parameter (y_c/h = 0.69) for stepped spillway. It is also observed that for all the models energy dissipation decreases with increase in operational head and increases with decrease in rise-tread ratio of steps and number of steps. Stepped spillway with combination of solid roller bucket and controlled stilling basin (Model E) showed energy dissipation of 92.40 % and maintained y_t in between 0.63 to 0.98 times y_2. The Model A and Model E dissipated 82 % and 92 % of average energy respectively. However Model B, Model C and Model D dissipated 60 to 70 % of average energy due to y_2 curve lies above y_t curve under controlled tail water condition. The value of $y_c / h < 0.8$ maintained the nappe flow over the ogee stepped spillway model [8].

The location of y_2 and y_t curve at operational head of 1.5 m, 4 m & 7 m for Model A and Model E is shown in Fig. 3.1 & Fig. 3.2 respectively. In Model A, y_2 curve lies above y_t curve upto unit discharge of 0.019 $m^3/s/m$ and later on y_t curve lies above the y_2 curve for unit discharge of 0.024 $m^3/s/m$. The ideal situation of y_2 curve & y_t curve is observed in Model E for discharge of 0.0069 m^3/s.

The Figure 3.1 shows that in Model A, y_2 is greater than y_t for lower discharge and for higher discharge y_2 is lower than y_t. y_t is increases with increase in unit discharge. Therefore the geometric condition in Model A is satisfied $Fr_1 > 4.5$ and achieves 88.81 % of average energy dissipation. The model A_2 is found to be best model as compared to A_1 & A_3. The energy dissipation of 93.12 % for unit discharge of 0.0176 $m^3/s/m$ is observed in the stilling basin. The observed Fr_1 is 4.87 (>4.5) indicating that the solid roller bucket functions best with the controlled end sill stilling basin.

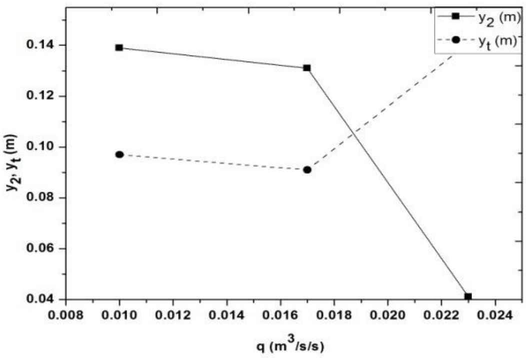

Fig. 3.1 Plot of y_2 and y_t curves of A_1, A_2 &A_3 Models

The Fig. 3.2 shows that y_2 curve lies above y_t curve for all the discharges. The y_2/y_1 ratio is more than 6.5 as well as y_t/y_2 ratio is found ideal. The Froude number is reduced due to the steps on spillway chute and there is transition of flow from supercritical to subcritical on it. The enhancement of energy dissipation in Model E is due to stabilization of hydraulic jump in the stilling basin. In this model the function of roller bucket is effectively observed for operational head of 1.5 m, 4 m & 7 m and the corresponding discharge ranging from 0.003 to 0.0069 m^3/s.

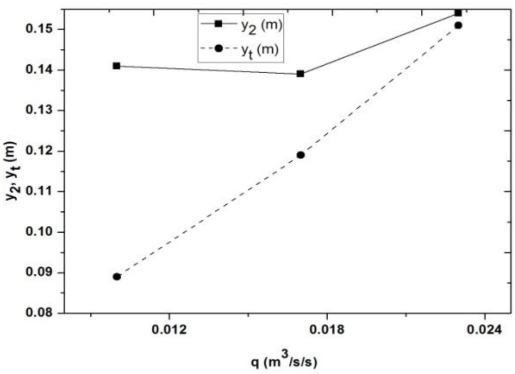

Fig. 3.2 Plot of y_2 and y_t curves of E_1, E_2 &E_3 Models

Thus the energy dissipation with solid roller bucket is observed effectively for ogee and stepped spillway. It is found that the physical model with modified stilling basin dissipated the maximum energy without controlling tail water depth for Model A and Model E. The model E dissipated maximum energy for all operating heads as compared to other models due to the submergence of hydraulic jump under tail water depth in the stilling basin. In stepped spillway model with modified stilling basin y_t is maintained in the range of 1.1 to 1.4 times y_2. Froude number also decreases with increase in head and discharge.

Table II. Performance of Ogee Profile Stepped Spillway Models

Model Description	Unit Discharge q ($m^3/s/m$)	Pre-jump Depth y_1 (m)	Post-jump Depth y_2 (m)	Tail Water Depth y_t (m)	Froude Number Fr_1	Sequent Depth Ratio y_2/y_1	Tail Water Depth Ratio y_t/y_2	Energy Dissipation $\Delta E/E_1$ %
A_1	0.01	0.009	0.139	0.097	4.02	3.6	0.697	82.92
A_2	0.017	0.018	0.131	0.091	4.87	3.7	0.694	93.12
A_3	0.023	0.039	0.041	0.141	6.4	3.65	3.439	90.39
B_1	0.007	0.031	0.101	0.091	1.44	3.5	2.935	76.95
B_2	0.0091	0.022	0.141	0.221	1.75	3.47	1.567	66.69
B_3	0.009	0.024	0.271	0.212	2.15	3.47	0.782	61.67
C_1	0.006	0.021	0.101	0.202	1.81	3.6	2	74.43
C_2	0.01	0.02	0.141	0.201	2.42	3.65	1.425	72.67
C_3	0.001	0.012	0.241	0.191	2.48	3.56	0.792	69.39
D_1	0.005	0.016	0.111	0.202	1.55	3.74	1.819	82.12
D_2	0.008	0.021	0.118	0.231	2.73	3.7	1.957	72.35
D_3	0.01	0.021	0.271	0.273	2.08	3.6	1.007	67.7
E_1	0.01	0.021	0.141	0.089	8.31	6.71	0.631	92.4
E_2	0.017	0.017	0.139	0.119	8.5	8.17	0.856	90.8
E_3	0.023	0.018	0.154	0.151	9.19	8.55	0.98	92.29

IV. CONCLUSIONS

In the present study experiments are performed on ogee stepped spillway in combination with solid roller bucket and controlled end sill stilling basin for varying heads and discharge. The solid roller bucket of this working model functioned effectively without controlling tail water depth in stilling basin. A tail water depth was maintained in range of 1.1 to 1.4 times sequent depth for all heads. This is the most ideal condition of tail water depth and sequent depth observed in stilling basin. The energy dissipation is consistently observed on spillway chute and attained maximum energy dissipation in stilling basin for nappe flow (y_c / h < 0.8). It has been observed that ogee profile stepped spillway model E_1 for 1.5 m head achieved 92.40 % of energy dissipation with non - dimensional parameter (y_c/h) of 0.69. Therefore it is concluded that the stepped spillway in combination with solid roller bucket and modified stilling basin (Model E_1) is the best model and gives the better performance for energy dissipation at all the operational head. Thus Model E is found more economical at higher discharge without controlling tail water depth.

ACKNOWLEDEGMENT

Experiments are performed in Fluid Mechanics Laboratory at AISSMS's College of Engineering, Pune.

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