Climate Change Adaptation: A Hydraulic Model Study to Improve the Spillway Discharge of Giritale Reservoir

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Abstract: **The Piano Key (PK) spillway constructed at Giritale in 2013, is the first of its kind in Sri Lanka. A capacity enhancement of the Giritale reservoir was required to overcome the frequent water shortages during cropping seasons and droughts. A decision was taken to enhance the capacity by increasing the crest level of the spillway and a new spillway of the PK type was introduced to satisfy this requirement. In this research, a model study was done to improve the discharge efficiency of such a PK spillway. Two models with different sectional arrangements were fabricated and later these were modified basically in crest shape. A total of four different models were tested to simulate the flow behavior over the spillway and the results were analyzed in order to find the head discharge relationship. The research focused on how to obtain a suitable PK model, among the models tested. The conclusion was that model 1b (among the models 1a, 1b, 2a, 2b) was the optimum model for the Giritale project.**

Keywords— Piano Key spillway, capacity, discharge efficiency, head-discharge, crest shape

I. INTRODUCTION

High intensity rainfalls, floods and droughts due to climate change have already become more frequent and severe in many parts of the country and are expected to further intensify in time to come [1], [2].The torrential rains and accompanying floods and landslides of December 2014 in various parts of the country affected over half a million people, raising concerns even about the impending presidential election. Critical flood conditions were observed at Nachchaduwa and several major reservoirs, where Nalanda dam was overtopped again. This is just four years after the disastrous floods of Dec 2010/Jan 2011, not forgetting the severe droughts of 2011 and 2012. These frequently recurring floods and droughts destroy agriculture and can easily affect the lives and livelihood of half a million or more people. As a possible adaptation to climate change in the irrigation and water resources sector, the government of Sri Lanka has adopted a novel twenty first century innovation, the Piano-Key (PK) spillway [1]. This has the twin capability of increasing water storage, while minimizing upstream inundation due to its enhanced low head flood discharge efficiency. Sri Lanka's first PK spillway was recently constructed at Giritale in 2013.

In order to improve the current capacity of the Giritale reservoir, it was decided to increase the crest level of the existing ogee spillway by 0.91m.With this increase, the reservoir capacity can be enhanced by $3.5x10^6$ m^3. However this will result in an afflux with the possibility of upstream inundation, which is not desirable. To overcome this, an alternate solution was proposed, which is the installation of a PK spillway instead of the existing ogee spillway. The special characteristic of a PK spillway is that it can give a higher discharge for a given head or can give a lower head for a given discharge, because it has a relatively larger projected spillway length. Thus it is possible to significantly reduce the afflux and thereby minimize the risk of upstream flooding. Fig. 1 shows the first spilling event of the newly constructed PK spillway at Giritale.

Fig. 1. PK Spillway - Giritale-Dec. 2014

II. Objectives

The main objective of this research is to find a solution to improve the discharge efficiency of a particular PK spillway, while keeping its afflux constant. While the final design should also consider the structural and economic aspects, the thrust of this paper is on investigating the hydraulic behavior of the spillway.

III. Literature Review

The PK spillway was first developed by Lemperiere and Ouamane [3] of Hydrocoop, a nonprofit making international association in France. This new spillway was designed to achieve the following objectives;

- Can be placed on existing or new gravity dams
- Will allow for a specific flow of up to 100 $m^3/s/m$
- can achieve flows four times greater than a Creager (Ogee) weir
- is structurally simple and easy to build with locally available resources

There are essentially four types (A, B, C and D) of PK spillways developed, with each of them having a certain geometrical shape as shown in Fig. 2.

The geometry of a PK spillway directly affects the flow behavior as the water passes through the weir. For convenience of understanding, a sample configuration of a PK spillway is shown in Fig. 3.The main geometric parameters of a PK weir are the transverse weir width W, the weir height P, the number of PK weir elements n (number of inlets and outlets), the lateral crest length B, the inlet and outlet widths W_i and W_o, the up and downstream overhang lengths B_u and B_d and the wall thickness T. As spillway discharge varies with the geometric parameters, it is necessary to focus on this fact when incorporating modifications for improvement [4], [5].

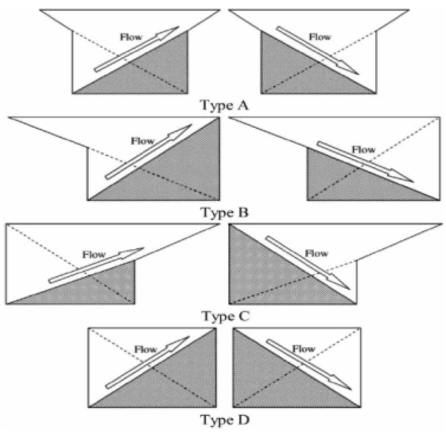

Fig. 2. Different types of PK weirs-cross sections [6]

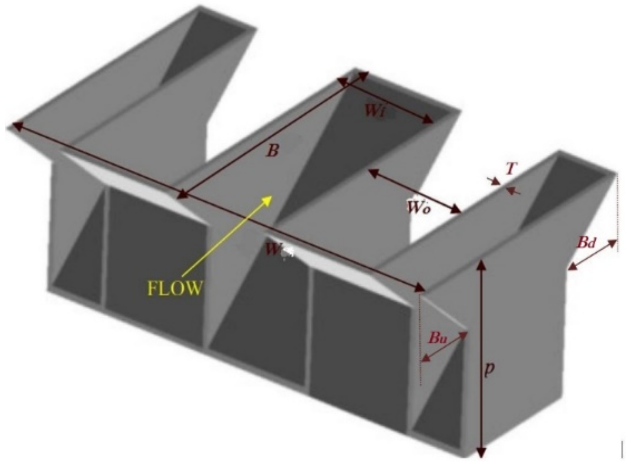

Fig. 3. 3D view of a PK spillway

When considering a design method for a PK spillway, it is mainly based on experimental results. With so many parameters, the design process is not as easy as for other common types such as the ogee spillway. The main problem with the PK spillway is that there is no proper design criteria yet developed due to the absence of a suitable theoretical approach [7].

Several researchers have found some relationships between geometrical parameters that improve the discharge efficiency of a PK spillway. The W_i/W_o ratio (See Fig. 4) is an important parameter that affects discharge efficiency which is also linked to the number of keys. It has been found that the optimum spillway which gives maximum discharge efficiency is when the W_i/W_o ratio is close to 1.25 [8].

The crest shape also plays a significant role in improving the discharge efficiency. Researchers have found that three kinds of shapes such as upstream quarter round, downstream quarter round and flat crest affect the discharge. Among those, the upstream quarter round is most efficient. However, the relative change in discharge efficiency, specific to each crest shape, was not specified [8].

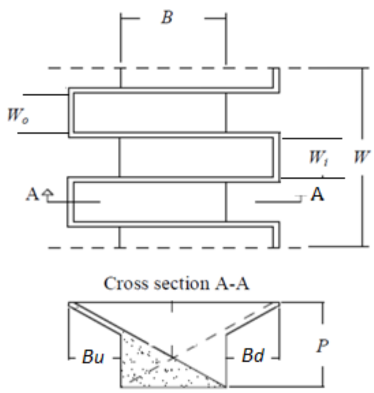

Fig. 4. Plan view & cross section

Reference [9] gives information about some pioneering work done and a detailed description of the PK spillway project at Giritale, with additional design information.

IV. METHODOLOGY

All model experiments were carried out at the Hydraulic Research Laboratory of the Irrigation Department. Models were set in a concrete flume as shown in Fig. 5.

Fig. 5. Concrete flume with the PK model

The model scale (M) was 1:15, both in the horizontal and the vertical directions between the model and the prototype. For velocities and discharges, the Froude number similarity was used and the relationship between the discharges of the prototype (Q_p) and the model (Q_m) is given by,

$$Q_p = Q_m . M^{2.5}$$

There were basically two models with four configurations which were tested as shown in Table I. Some modifications in crest shape were introduced in order to study the discharge behavior.

TABLE I. BASIC PROPERTIES OF EACH MODEL

Model type	Number of keys (N)	Inlet outlet key ratio (W_i/W_o)	Inlet slope (S_i)	Outlet slope (S_o)	Spillway height (P) in cm
1	3	1.35	27°	27°	18
2	4	1.25	27°	27°	18

The following notations were introduced for each type for convenient identification.

- PK-1a – Basic model
- PK-1b – PK-1a with modified crest shape (half round) at upstream and downstream
- PK-2a –PK-1a with an additional key.
- PK-2b – PK-2a with modified crest shape -downstream only

The hydraulic performance of all these models was studied by varying the discharges. In order to study the flow behavior, the head and discharge were measured and a rating curve for each model was developed.

V. RESULTS & DISCUSSION

The rating curve between head and discharge for each model is presented in Fig. 6 [10]. Model PK-1b has a relatively higher discharge than PK-1a for a given head, the reason being the near half round crest shape. Likewise PK-2b gave a higher discharge than PK-2a for a given head. Model PK-2a generally gave a higher discharge than PK-1a because the projected length of PK-2a is greater due to the additional key.

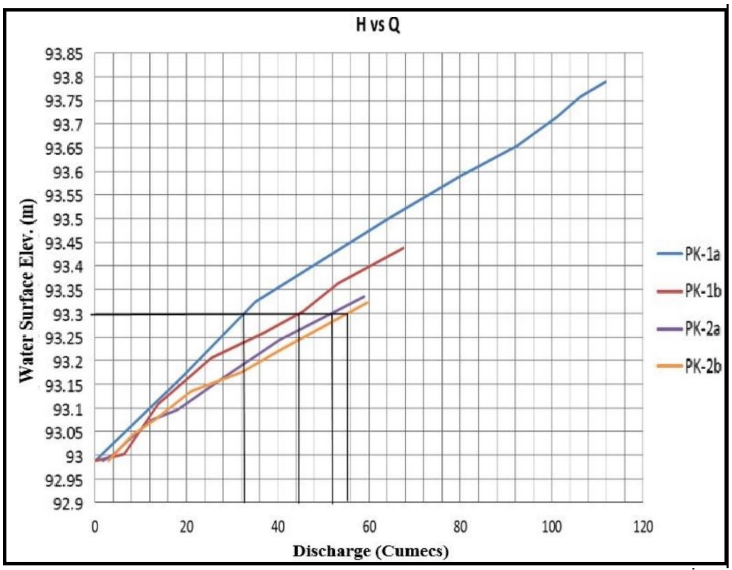

Fig. 6. Head-Discharge variation

In order to compare the weir coefficients (C) of each model against its heads (H), the C vs. H/P graphs are plotted, where P is the model height as in Fig. 7. The higher C values indicate a weir with higher discharge efficiency hydraulically [10].

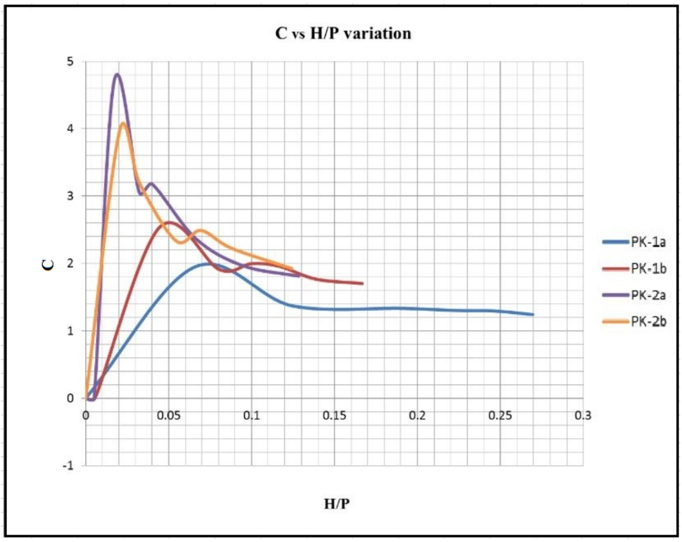

Fig. 7. C vs. H/P variation

The graph shows that both PK-1b and PK-2b give higher C values than PK-1a and PK-2a respectively, when H/P is greater than 0.08. Furthermore, PK-2a gives a higher C value than PK-1a. This clearly shows that the crest shape and the number of keys which increases projected spillway length, directly influence the weir coefficient, confirming other research findings [8].

The hydraulic performance of each model is summarized in Table II. Model PK-1a was taken as the reference model and all others were compared with respect to PK-1a. All discharges included in Table II are taken from Fig. 6 for a water surface elevation of 93.3 m MSL as an example. The corresponding H/P value for the water surface elevation is 0.113 and the C values are taken from the graphs of Fig. 7.

TABLE II. HYDRAULIC PERFORMANCE OF EACH MODEL

Model No.	Discharge (Cumecs)	As a difference with the PK-1a	Weir coefficient- C_d	As a difference with the PK-1a
PK-1a	35	-	1.4	-
PK-1b	45.5	+30%	1.9	+35.7%
PK-2a	59	+67%	1.8	+28.6%
PK-2b	59.6	+70%	2.0	+75%

According to results in Table II, the best hydraulic performance is shown by PK-2b because its spillway length is highest and its crest shape is hydraulically better.

However, when selecting a suitable spillway for Giritale, the economic and structural aspects also had to be addressed and hence a PK-1a type spillway was constructed in 2013. However it can be seen that a PK-1b with the modified crest shape would have given a significantly better hydraulic performance.

During the floods of 2011, the nearby highway was subject to inundation [9]. However with the new PK spillway and the raising of the road level, no flooding of the highway was reported in the floods of 2014.

VI. Conclusions

The Piano Key Spillway at Giritale, the first of its kind in Sri Lanka, has demonstrated its efficiency and potential as an innovative adaptation to climate change, in the irrigation and water resources sector.

The model studies have clearly shown that the number of keys and the crest shape of the weirs were two parameters that had a significant bearing on model performance. Of the four models tested, PK -2b was found to give the best hydraulic performance. However, when the economic and structural aspects too were considered, PK -1b could be deemed to be the optimum case.

The PK spillway shows great promise in significantly improving the existing flood discharge capacities of spillways at dams such as Nachchaduwa, which experienced critical conditions in 2011 and 2014.

Acknowledgment

The authors are grateful to Eng. A.L.M.Cassim, Director, Hydraulic Research Laboratory, Department of Irrigation for providing the required facilities and making other arrangements to carry out the model studies. The assistance given by Eng. N.A.I.U.K.Nissanka, Mr. A.I.M.Raji and the technical staff of the Hydraulic Research Laboratory, is also gratefully acknowledged.

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