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Assessment of Discharge Enhancement of Piano Key and Rectangular Labyrinth Spillway and Hydraulic Comparison

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Abstract: ***throughout history dams have been important structures in water storage. To avoid overtopping, damage, and or failure of a dam, adequate spillway is needed to release excess water from upstream floods. Researchers found that spillways have to be made nonlinear in order to reach an economic structure with high performance. A piano key weir is one of the best solutions. The piano key or PK weir represents a relatively new hydraulic structure in both research and practice. Piano key weirs are the modified and developed labyrinth spillways which can discharge greater volume of water than the common spillways in limited width and can be used as economic structures with high efficiency. There is currently a limited understanding regarding the influence of the large number of Rectangular Labyrinth and Piano Key weir geometric parameters on hydraulic performance. By using laboratory-scale physical models, the hydraulic efficiency of the recommended RL and PK weir design was obtained and necessary comparisons were made. The physical models of RL and PK weir are designed based on froudian similarity. Fabricated and tested in hydraulic laboratory and moreover the results are evaluated by comparing an actual RL and PK weir discharge to that theoretically obtained for a sharp crested weir with crest length equal to the width of PK weir for a given hydraulic head. Until today only preliminary design procedures are available which cannot yet be generalized. The still ongoing research on this complex hydraulic structure is a challenge for many scientists all over the world. Despite of this, several prototypes have been installed successfully over the last years on existing dams which enhance efficiently the flood release capacity.***

I. INTRODUCTION

Labyrinth spillways are almost as old as dam engineering. They have been installed on numerous hydraulic structures thanks to their simple structural concept and their increased specific discharge capacity. Moreover, as free flow spillways, their operation is quite reliable compared to gated ones. For instance, labyrinth weir on Beni Badhel dam (Algeria), which was built before the Second World War, has an incredibly high hydraulic performance with a discharge capacity 12 times higher than standard linear ogee crest spillway. More recently, the labyrinth weir built on Ute dam (USA) is a very large structure able to discharge a design flood of 15,600m3/s over a width of 250 m. In addition, innovative fuse plug spillways are often based on labyrinth shaped units. Although labyrinth spillways appear as a very good technico-economical compromise, only 0.1% of large dams are equipped with such weirs. The main reason for this small rate is that traditional labyrinth weir can generally not be installed on top of concrete gravity dams because they require a large foundation surface. In 2003, Lempérière and Ouamane proposed an improved concept of traditional labyrinth spillway, with alveoli developed in overhangs from a reduced support area. Due to a plan view looking like piano keys, it was consequently called Piano Key Weir (PKW). The main advantage of this work is that it can be installed at the top of main existing concrete dams. More recently, extreme flood issues have become more and more acute due to both increasing society demand for safety and revised hydrological calculations. The requirement for performing and reliable spillways has consequently become higher, leading to a rehabilitation need of numerous existing dams. In this context, the PKW appears as an interesting solution to increase the hydraulic capacity of spillway devices. This innovative concept was implemented in 2006 with the construction of the first PKW on Goulours dam (France) owned by Electricité de France (EDF). Following this realization, four other PKWs were built in France between 2007 and 2010 and several other projects are under design or construction in France and other countries (India, Vietnam, Burkina Faso…). These projects show that dam engineering is currently experiencing a strong revival of labyrinth oriented weirs.

II. AIM AND OBJECTIVES

To develop a model of rectangular labyrinth spillway and piano key spillway from various data sources available of dams and

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prototype models studied across the globe.

To study and analyze the discharge efficiency of a given piano key spillway from the physical model and its release capacity related to as sharp-crested weir.

To study and analyze the discharge efficiency of a given rectangular labyrinth spillway from the physical model and its release capacity related to piano key spillway

To compare hydraulic performance of rectangular and piano key spillways and draw conclusions.

To study the change in the discharge capacity of the weir due to the improvisations made.

To establish the head- discharge relation for the different models.

To establish and analyze the discharge and coefficient of discharge relation for the different models.

III. LITERATURE REVIEW

A. A.J. Schleiss (2011) presented paper on From Labyrinth to Piano Key Weirs. A Historical Review.

Free crest spillways are hydraulically efficient and safe in operation. Since their discharge capacity is directly proportional to the crest length several types have been developed with the purpose to increase the length of the latter. Among these types traditional labyrinth weir spillways have been studied and used for a long time. Their hydraulic performance and the effect of the involved geometrical parameters are well known. Nevertheless, their design still has to be based on experimentally derived and generalized performance curves. The recently introduced Piano Key weirs present clear advantages regarding hydraulic performance and construction costs compared to classical labyrinth weirs. Especially its small foot-print makes the PK weir an efficient and cost effective solution for the increase of the flood re-leasing capacity at existing concrete gravity dams. Until today only preliminary design procedures are available which cannot yet be generalized. The still ongoing research on this complex hydraulic structure is a challenge for many scientists all over the world. Despite of this, several prototypes have been installed successfully over the last years on existing dams which enhance efficiently the flood release capacity. As stated by Lempérière and Ouamane (2003), the Piano Key weir was originally developed by Blanc of the University of Briska (Algeria), and Lempérière of Hydrocoop (France), to facilitate and improve the performance of labyrinth-type weirs installed on smaller spillway footprints. Over 100 PK weir model studies have been completed since 2000 (Lempérière 2009), although data are not available for all studies. Construction of the first prototype PK weir, Goulours dam in France, was completed in 2006; construction of the second prototype PK weir, Saint-Marc dam in France, was completed in 2008 (Laugier 2007, 2009).

B. lemperiere (2009) Presented Paper on Head-Discharge Relationship for Piano Key Spillway Design

Despite previous studies outlined above, no generally accepted standardized design procedure is currently available for PK weirs. This is due, in part, to the large number of geometric parameters (e.g., crest shape, parapet wall, fillets, Wi /Wo, Bi /Bo, sloping floors, overhangs, etc.) and a limited understanding of their influences on the PK weir discharge efficiency. Despite the absence of a standard design procedure, Hydrocoop (France), a non-profit dam spillways association, who is responsible for the majority of the literature available on PK weirs, has developed a PK weir geometry they consider to be near optimal (Lempérière 2009), though insufficient support data have been published for independent verification. The design recommended by lemperiere (2009) consists of line drawing closely resembling the basic PK spillway structure although this design does not include guidelines for all of the needed design parameters (e.g., wall thickness, crest shape, parapet wall, fillets). Along with the design, Lempérière (2009) gives as an estimate for the PK weir head-discharge relationship.

$$q = 4.3\sqrt{Pm} \qquad (1)$$

C. Machiels, S. Erpicum, P. Archambeau, B. Dewals & M. Pirotton (2011) presented paper on Influence of the Piano Key Weir Height on its Discharge Capacity*

Within the framework of Piano Key Weir (PKW) development, the hydraulic optimization of its geometry seems essential. First systematic studies of all the geometrical parameters of the PKW highlight a more important influence of some parameters compared to other ones. A former study led, at the University of Liège, on a large scale model of PKW highlights the main influence of the inlet cross section on the global discharge capacity of the weir. Based on this finding, the geometrical parameters influencing the inlet cross section seem to be the most influential parameters of the weir efficiency. This paper presents results of an experimental study using models of PKW with varying height. The mean non-dimensional parameters characterizing the geometry of the models are maintained constant, only varying the slope of the alveoli. The results of the 7 models studied, with a wide range of slopes (height over length) from 0.25 to 1.5, are presented. Based on these results, an analytical formulation of the unit discharge over a

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PKW as a function of its height is developed. In order to design PKW, an experimental study of the influence on the release capacity of three geometrical parameters (Wi/Wo, Bo/Bi and P), highlighted as main influent ones by former experiments, has been undertaken. The results of experiments led on models with varied inlet slope, induced by variation of the weir height, highlight the interest on the hydraulics standpoint of increasing the inlet slope to increase the release capacity of the weir. However, over a limit slope near 1.2, the increase of the slope doesn't more change the release capacity of the PKW.

IV. METHODOLOGY

In present study, physical model experiments have been conducted on both the rectangular labyrinth and piano key spillway models. The methodology applied in the present study consists of dimensional analysis, experimental setup, testing procedures and then analysis of data and results.

A. Dimensional Analyses

Discharge over weirs in general is a function of three groups of variables: Geometric characteristics of the model, Fluid properties (density ρ, dynamic viscosity μ, and surface tension σ), and Flow characteristics (the total head H, the gravitational acceleration g). the geometric parameters of the PKW include the weir height P, the total weir crest length L, the lateral weir crest length B, the channel or transverse width W, the upstream key cantilever (overhang) lengths b, and the up- and downstream key widths b and a. Notations of this study are in agreement with the naming convention of Pralong et al. In the present study, the effect of the nose length on the efficiency will be studied as the parameter (B_{in} /B_{out}), since the nose is located under the upstream overhang and its length extend with the length of the upstream overhang. The discharge over a PKW for free flow depends on:

$$Qact = f(\rho, g, \mu, \sigma, H, L, P, P', W, a, b, Sin, Sout, \alpha, t, R)$$

Where f is a functional symbol. Since the flow in nature is turbulent, and occurs at a relatively large head, it can be assumed that viscosity μ, and surface tension σ is insignificant variables. If for all tests H > 30 mm, the effects of surface tension on discharge are small. To describe the discharge capacity of a PK spillway, its discharge coefficient (CPKW) is presented according to the common spillway formulation referred to the total developed crest length (L).

$$C_{PKW} = \frac{Qpkw}{L.H^{\frac{3}{2}}\sqrt{2g}} \qquad (2)$$

The PK spillway discharge coefficient CPKW can then be expressed as a function of dimensionless geometric and hydraulic parameters.

$$C_{pkw} = f\left(\frac{l}{w}, \frac{a}{b}, \frac{p}{a}, \frac{p}{p'}, \frac{t}{p}, \frac{t}{R}, \frac{H}{a}, S_{in}, S_{out}, F, R_e, W\right) \qquad (3)$$

The Reynolds number (Re) and Weber number (W) are sufficiently large to avoid fluid viscosity and surface tension scale effects. Due to the systematic subcritical approach flow conditions and the Froude similarity, gravity effects are correctly simulated. The studied PK spillway is rectangular shaped (α = 90°) and thus α is not included in the analysis. In a PK spillway the parameters a, b, B, L, and W are correlated as.

$$\frac{L}{W} = \frac{a+b+2B}{a+b} \qquad (4)$$

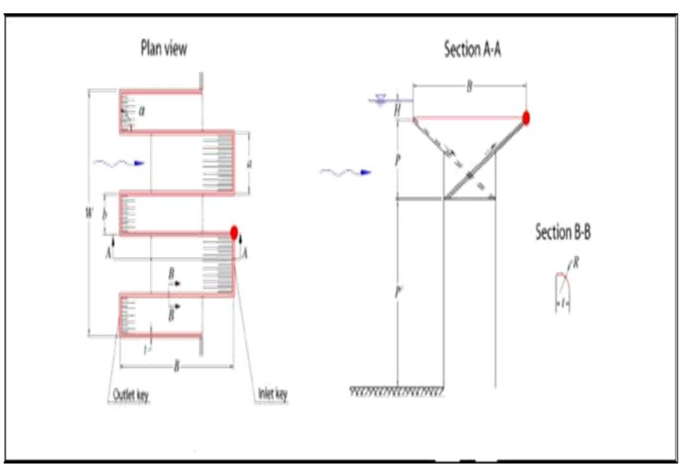

Fig 1 cross section details of spillway

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V. EXPERIMENTAL SETUP

Test was conducted in a 0.40 m wide x 0.50 m deep x 7.83 m long rectangular flume. Water entered the flume though a head box containing a flow diffuser, a vertical baffle wall and a floating surface wave suppressor to increase approach flow uniformity. A point gauge was used to measure head. A Calibrated triangular right angled V-notch located at the end of flume is used to measure the discharge of PK spillway. The spillway wall was fabricated using 6 mm thick acrylic sheet. The spillway was installed in the flume on a short, adjustable base and leveled using surveying equipment. An overview of the test facility with the PK spillway installed is presented in Fig (2).

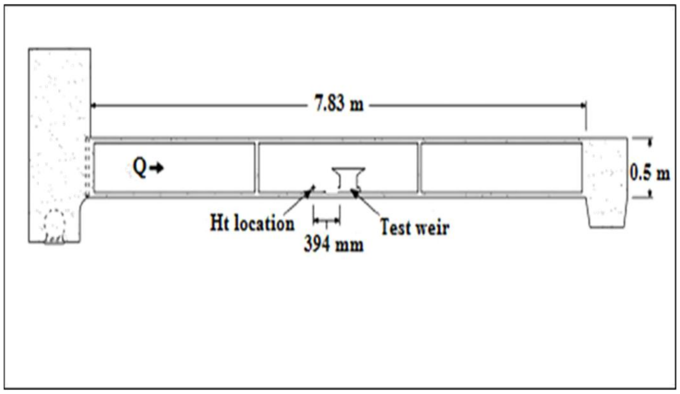


Fig.2 Test Flume Side View

VI. TESTING PROCEDURE

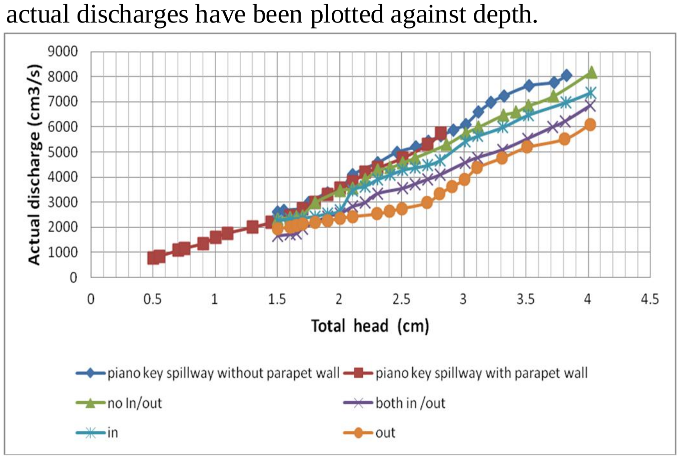
The spillway crest centre line lengths and spillway heights were physical measured. Clean water was used for testing. The water temperature ranged from 77 to 90°F. To reduce the potential influence of thermal contraction on spillway hydraulic performance, water was allowed to flow through the flume for approximately 30 min prior to establishing crest elevation references and collecting head-discharge data. The upstream piezometric head (H) data were determined using the point gauge after the upstream water surface was allowed to stabilize. To verify that stable flow conditions had been achieved, a minimum of three consecutive point gauge measurements were taken for each flow rate. If the H values were not in agreement, then more stabilization time was allowed and the measurements were repeated. The total head (Ht) was calculated by summing the measured H and the velocity head (V2/2g) [V is the average approach velocity at the H measurement location].The approach velocity V is given by Eq. (5)

$$V=Q/W*H \quad (5)$$

VII. ANALYSIS OF DATA AND RESULTS

A. *Variation of Discharge with Head*

Since discharge Q is proportional to h (for a PK and RL weir), the variation of discharge v/s h is linear in nature and is proportional to $h^{3/2}$ (for a normal weir) the graph will be curvilinear with concave upward. To comparatively study the nature of a piano key weir w.r.t. a normal weir, first of all the actual discharges have been plotted against depth.



Variation of discharge (Q) versus ***H*** for various PK and RL geometry

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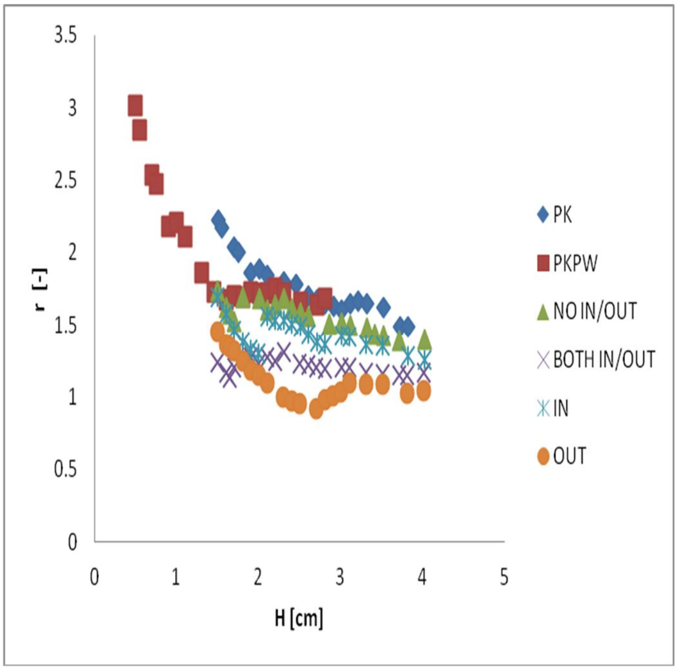
B. Variation of Discharge Enhancement Ratio with Head

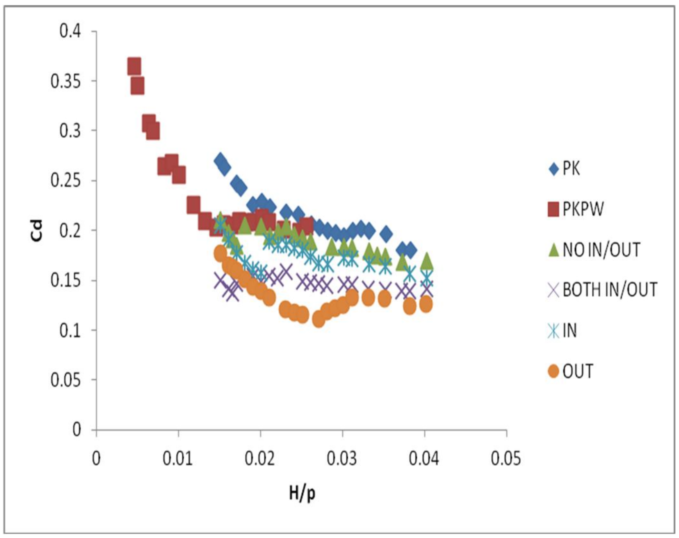
In order to see the enhancement in efficiency between nonlinear weirs (rectangular labyrinth and piano key spillway)of different geometry, a comparison must be made between the discharge enhancement ratio and total head, to evaluate the most economical and efficient geometry.



Variation of discharge enhancement ratio ® versus ***H*** for various PK and RL geometry

C. Variation of Discharge Coefficient with Head to Height Ratio

for different geometry of rectangular labyrinth and piano key spillways having same inlet to outlet key width, the efficiency of models were studied by finding the coefficient of discharge for different head to height ratio.



Variation of coefficient of discharge (C_d) versus H/P for various PK and RL geometry

VIII. CONCLUSION

A. Piano key weirs are the modified and developed labyrinth spillways which can discharge greater volume of water than the common spillways in limited width or In order to maximize the unit-discharge per available width both the physical models (nonlinear) were tested and necessary conclusions were drawn.

B. The increase in efficiency of discharge can be indicated as function of discharge enhancement ratio and was found to be greater for both piano key spillways with and without parapet wall than all rectangular labyrinth spillways.
C. Rectangular labyrinth spillway and Piano Key spillway increased the discharge capacity two to three times with respect to Sharp-Crested spillway.
D. Discharge enhancement ratio (r) was found to be function of the head above crest level. It is highly efficient for low heads and its benefits over Sharp-Crested Spillway reduce as head goes on increasing
E. . The addition of parapet wall (10% of height) above the crest of piano key spillway increased the discharge considerable for the same head.
F. The development of head at the upstream of the models in case of submergence i.e. at full discharge of the pump was not very high; which was an expected result
G. Maximum discharge enhancement ratio (r) was observed for piano key spillway with parapet wall calculated as 3.009 at H/P = 0.045 or H/a =0.0105
H. Discharge enhancement ratio(r) for Rectangular labyrinth spillway for all discharges and for all geometry changes remained one times with respect to sharp crested weir.
I. Minimum discharge enhancement ratio (r) calculated to be 0.921 at H/P = 0.027.
J. The coefficient of discharge (Cd) for piano key spillway (both with parapet wall and without) has higher values than Rectangular labyrinth spillway of different configuration.
K. . Maximum co efficient of discharge (Cd) was calculated as 0.364 for H/p = 0.00454 which corresponds to piano key spillway with parapet wall
L. . The behavior of two geometrically changed models (rectangular labyrinth and piano key) at lower discharges was not much remarkable
M. The higher values of co efficient of discharge (Cd) indicate most efficient models where we can conclude that PK spillway is more efficient than RL spillway
N. It increases live storage capacity of reservoir by passing given discharge with lesser head as compare to linear spillway.

IX. ACKNOWLEDGMENT

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REFERENCES

[1] Tullis, J. P., Amanian, N., and Waldron, D. (1995). “Design of labyrinth spillways.” J. Hydraul. Eng., 121(3), 247–255.
[2] M. leite Riberi; J.L. Boillat; G.singhal and sharma, “discharge capacity of piano key spillway; journal of hydraulic engineering (ASCE) vol 138, no.2,2012
[3] A.J. Schleiss (2011). “From Labyrinth to Piano Key Weirs. A historical review.” International Workshop on Labyrinth and Piano Key Weirs, Liège, Belgium..
[4] Machiels*, S. Erpicum, P. Archambeau, B. Dewals & M. Pirotton (2011) “Influence of the Piano KeyWeir height on its discharge capacity.” Laboratory of Hydrology, Applied Hydrodynamics and Hydraulic Constructions(HACH), Liège University, Liège, Belgium
[5] M. Anderson1 and B. P. Tullis, ’ piano key spillway: reservoir vs channel application ‘, journal of irrigation and drainage engineering (ASCE) vol138, no.8,2012
[6] A. Ouamane (2003-12) “Nine years of study of the Piano Key Weir in the university laboratory of Biskra”. Laboratory of Hydraulic Planning and Environment, Biskra, Algeri
[7] Lempérière, F. (2009). “Head-discharge relationship for piano key spillway design.” journal of irrigation and drainage engineering (ASCE).
[8] Anderson, R.M. and Tullis B. P. 2011. Influence of Piano Key Weir Geometry on Discharge. Proc. International Workshop on Labyrinth and Piano Key Weirs, Liège, Belgium.
[9] Blancher, B., Montarros, F. and Laugier, F. 2011. Hydraulic comparison between piano-keys weir and labyrinth spillways. Proc. International Workshop on Labyrinth and Piano Key Weirs,Liège,Belgium