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PIANO KEY WEIRS AS EFFICIENT SPILLWAY STRUCTURE (*)

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(*) *Déversoir en touches de piano – Un évacuateur de crue efficace.*

1 INTRODUCTION

With increasing of hydrological data records and the development of technologies for flood discharge estimation, as well as higher requirements on dam safety issues, a large number of existing dams require spillway rehabilitation to improve their hydraulic capacity. For such projects, the Piano Key Weir (PKW) is an efficient alternative. When compared to standard labyrinth weirs, this structure provides a longer effective crest length for a given spillway width, with the advantage that a PKW can be mounted on the top of most existing dams, due to its reduced base surface [1, 2].

Although the hydraulic design and optimization process of PKWs are today supported by physical modelling of case studies [3, 4, 5, 6], systematic basic experiments performed in laboratory channels were important to understand their hydraulic behavior [7, 8, 9, 10]. Most of the experiments consider only one sectional part of the PKW, with uniform approach flow conditions. The three-dimensional effect of the lateral weir ends, characterizing a typical reservoir inflow, is consequently not considered. As a result of these systematic tests, some procedures for designing PKWs are proposed in literature. Among these methods, a simplified formulation for calculating the hydraulic capacity of A-type PKWs [10] is based on the most important geometrical dimensionless parameters of PKWs, i.e, L/W, W_i/W_o, P_i/P_o and H/P_i, (Fig. 1).

The objective of this paper is to present some selected results of systematic experiments performed in a laboratory channel, focusing on the number of PKW units and the influence of the parapet walls.

2 RELEVANT GEOMETRICAL PARAMETERS

The standard nomenclature as defined in [11] is used herein (Fig. 1), with L= developed crest length, B= streamwise length, W= transversal width, P= vertical height, L= development length, T_s= walls thickness and P_{px}= height of parapet walls. Furthermore, the subscript i refers to the inlet key, i.e. the key that is filled with water for a reservoir level at the PKW crest elevation, and the subscript o to the outlet key, i.e. the "dry" key for the same reservoir level.

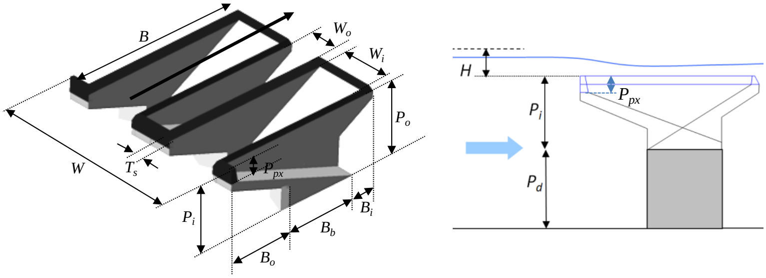


Fig. 1
Nomenclature and characteristic geometry of A-type PKWs [11]
Nomenclature et géométrie caractéristique d'un PKW type A [11]

3 EXPERIMENTAL SET-UP

Systematic physical experiments were performed in a straight channel of 40 m length, 2 m width and 1 m height. A sufficiently long parallel approach flow reach was provided to avoid flow disturbance at the PKW section. Experiments were divided in two series:

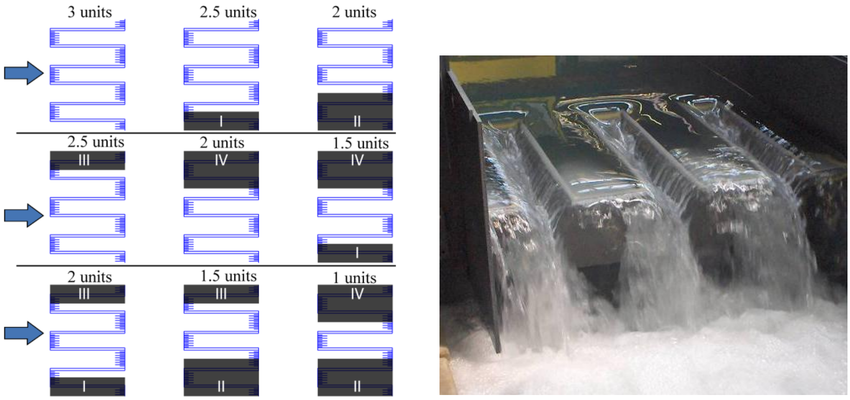
In the first series (unit configurations), a 1 m wide PKW with 3 units was installed at the channel center (Fig. 2), 0.50 m above its bottom (P_d=0.50 m); a unit being composed by of one inlet and one outlet keys [11]. The PKW model, constructed with 0.02 m thick PVC plates, was 0.217 m high. The ratio between the widths of inlet and outlet keys W_i/W_o was 1.25, with W_i=0.163 m and W_o=0.130 m. Nine different configurations were tested (Fig. 2, the black areas indicate closed PKW parts). Each of them is characterized by a certain number of active PKW units. For all tests, the ratio L/W remained constant.

In the second series (alternative configurations), a PKW with 1.5 units was installed in the same channel. A "reference PKW configuration" (Nr 1, Table 1) was thus defined, corresponding to the following geometry:

- W_i/W_o=1.25, with W_i=0.163 m and W_o=0.130 m;
- L/W=5, with W=0.5 m;
- P=0.217 m;

Different configurations were tested, as indicated in

Table 1. First, the slopes of the keys were modified and four alternatives were tested, i.e. (1) P_i=P_o=0.217 m, (2) P_i=0.217 m and P_o=0.157 m, (3) P_i=0.157 m and P_o=0.217 m, and (4) P_i=P_o=0.157 m. Furthermore, eight different parapet walls were tested exceeding the crest of the reference configuration (Nr 5 to 12).



Units config.	0	I	I, III	I, IV	IV	II, IV	II	II, III	III
Units #	3	2.5	2	1.5	2	1	2	1.5	2.5
L [m]	5	4.17	3.33	2.5	3.33	1.67	3.33	2.5	4.17
W [m]	1.00	0.83	0.67	0.50	0.67	0.33	0.67	0.50	0.83
L/W	5.01	5.01	5.00	5.01	5.00	5.02	5.00	5.01	5.01

Fig. 2
Configurations with different unit numbers and photo of 3 units set-up
Configurations à différents nombres d'unités d'alvéoles et photo du modèle à 3 unités

Table 1
Summary of main geometrical parameters of the alternative configurations

Nr.	Alternative configurations	S_o [°]	S_i [°]	P_o [m]	P_i [m]	P_{pxo} [m]	P_{pxi} [m]
1	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=1.33	26.6	26.6	0.217	0.217	0.00	0.00
2	L/W=5, W_i/W_o=1.25, P_i/P_o=1.38, P_i/W=1.33	19.9	26.6	0.157	0.217	0.00	0.00
3	L/W=5, W_i/W_o=1.25, P_i/P_o=0.72, P_i/W=0.96	26.6	19.9	0.217	0.157	0.00	0.00
4	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=0.96	19.9	19.9	0.157	0.157	0.00	0.00
5	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=1.58	26.0	26.0	0.257	0.257	0.04	0.04
6	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=1.70	26.0	26.0	0.277	0.277	0.06	0.06
7	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=1.33	19.0	26.0	0.197	0.217	0.04	0.00
8	L/W=5, W_i/W_o=1.25, P_i/P_o=0.84, P_i/W=1.33	26.0	26.0	0.257	0.217	0.04	0.00
9	L/W=5, W_i/W_o=1.25, P_i/P_o=0.78, P_i/W=1.33	26.0	26.0	0.277	0.217	0.06	0.00
10	L/W=5, W_i/W_o=1.25, P_i/P_o=0.93, P_i/W=1.58	26.0	26.0	0.277	0.257	0.06	0.04
11	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=1.70	26.0	32.0	0.277	0.277	0.06	0.00
12	L/W=5, W_i/W_o=1.25, P_i/P_o=1, P_i/W=1.70	26.0	26/45	0.277	0.277	0.06	0.00

4 RESULTS

4.1 DEFINITIONS

In order to analyze the efficiency of a PKW (subscript *PKW*), a comparison to a linear sharp-crested weir (subscript *S*) with crest length *W* was performed [9, 10]. A discharge enhancement ratio *r* between the PKW discharge (Q_{PKW}) as measured on the model and a computed linear sharp-crested weir discharge (Q_S) as reference was considered:

$$r = \frac{Q_{PKW}}{Q_S} \quad [1]$$

4.2 EFFECT OF PKW UNITS NUMBER

Fig. 3 shows the discharge enhancement ratios *r* of the different unit configurations as function of H/P_i. An error bar (+/- 5%) is added, referring to configuration 0. Results show that all configurations have a similar behavior. The highest difference between the points is less than 5%. It can therefore be concluded that the number of units does not affect the unit hydraulic behavior, so that sectional model set-ups including only 1.5 units are representative for multi-units PKWs.

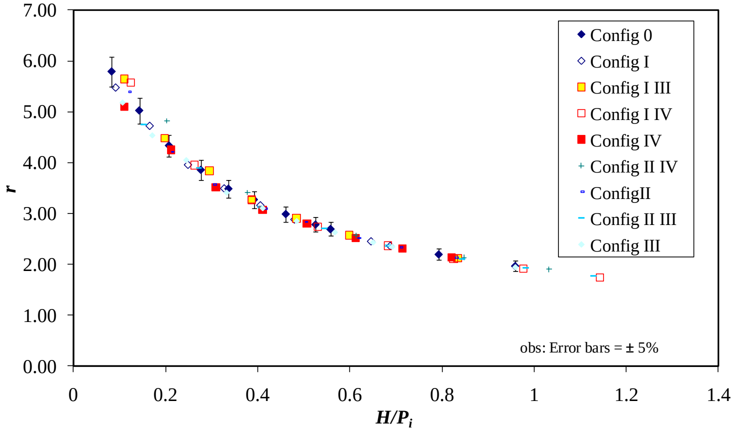


Fig. 3

Discharge enhancement ratio *r* vs. H/P_i for reference configuration PKWs with different unit numbers

Rendement r en fonction du rapport H/P_i *pour des PKWs à configuration de référence possédant différents nombres d'unités d'alvéoles*

These results indicate that the specific unit discharges of the reference configurations are similar. A condition is however, that the flow approach conditions are uniform. Note that the three-dimensional flow patterns close to the end of the PKWs may influence the specific discharge in general application cases.

4.3 EFFECTS OF PARAPET WALLS

Discharge enhancement ratios *r* as a function of H/P_i resulting from eight different parapet's configurations (Nr 5-12,

Table 1) are compared with the reference configuration (Nr. 1 in Table 1). The results presented in Fig. 4 show that the influence of the parapet is not significant.

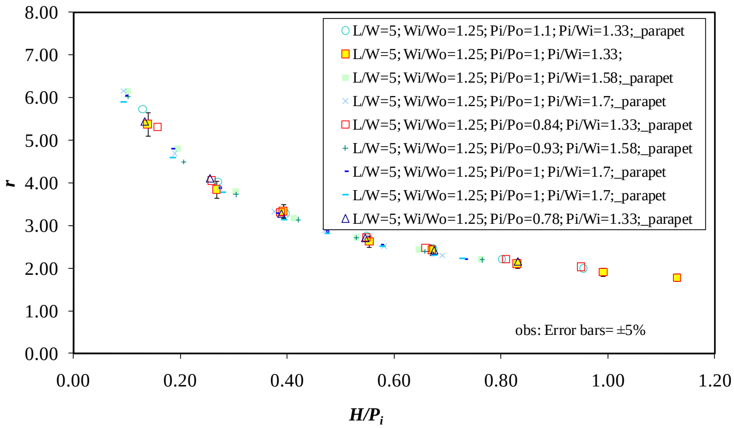


Fig. 4

Discharge enhancement ratio *r* vs. H/P_i PKWs with parapet walls (_parapet)

Rendement r vs. H/P_i pour les PKWs avec rehausse (_parapet)

The same analysis was conducted considering H/P_o (Fig. 5). Results show important differences between the configurations. However, most of the differences are due to an increase of P_i. A parapet wall in the inlet key leads to an increase in P_i and therefore an expected improvement in performance if the discharge enhancement ratio is expressed as a function of H/P_o.

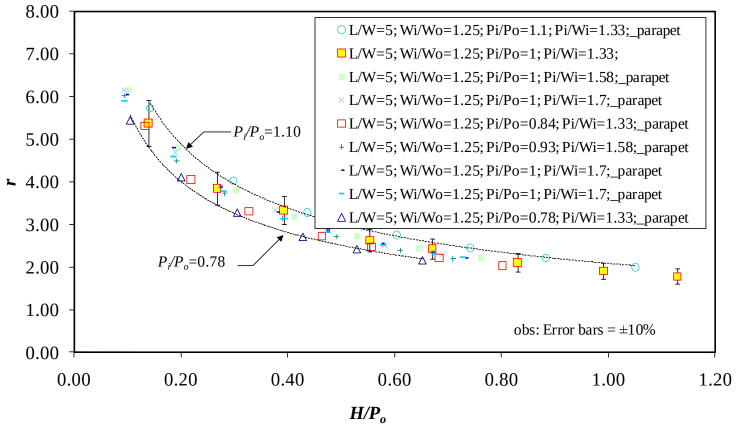


Fig. 5

Discharge enhancement ratio r vs. H/P_o for PKWs with parapet walls (_parapet)

Rendement r vs. H/P_o pour les essais avec rehausse (_parapet)

Results presented in Fig. 4 and Fig. 5 may be somehow misleading given the mix of parapets effect, P_i and P_o. To analyze the effect of the parapet exclusively on the outlet keys, the r-values of configurations 1-4 (without parapets) were compared to the results of configuration 7 (parapet only at outlet key). Fig. 6 shows that the presence of this parapet improves the performance of PKWs. For the same value of H/P_i, the PKW with parapet and P_o=0197 m (5th symbol in Fig. 6) has a similar efficiency as the PWK without parapet and P_o=0217 m (1st symbol in Fig. 6).

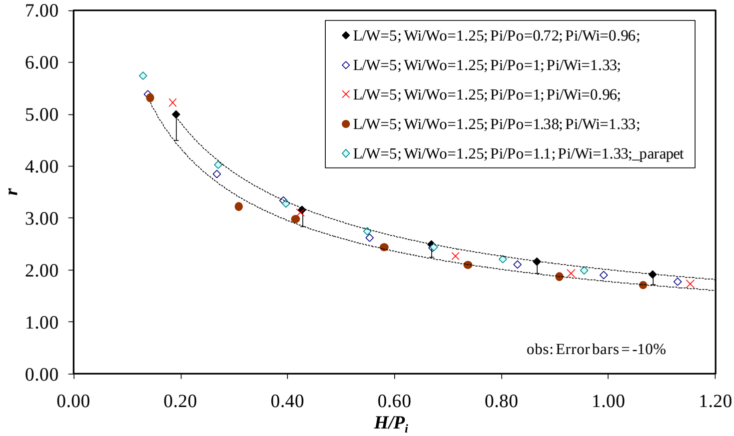


Fig. 6

Discharge enhancement ratio *r* vs. H/P_i for the tests with different P_i and P_o, and parapet walls on outlet keys (_parapet)

Rendement r vs. H/P_o *pour les essais avec différentes valeurs de* P_i *et* P_o *et rehausses (_parapet) sur l'alvéole de sortie*

CONCLUSIONS AND RECOMMENDATIONS

The hydraulic behavior of PKWs was analyzed on the basis of systematic experimental tests. The considered parameters are: the number of units and the presence of parapet walls. The main results are:

- For identical normal approach conditions, the number of PKW units does not affect the specific discharge per PKW-unit. Thus, the results obtained with 1.5 units are applicable proportionally to higher units numbers
- Parapet walls on the inlet keys are not effective. It can be compared to an increase in the height of the key. However, the presence of the parapet on the outlet key improves slightly the efficiency of a PKW.

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SUMMARY

Several existing dams require spillway rehabilitation to increase their hydraulic capacity. There, a PKW is an efficient inlet structure. As compared to a standard labyrinth weir, it provides longer effective crest lengths for a given spillway width. Beside this, a PKW may be mounted on top of existing concrete dams, due to its reduced base surface. The present paper analyses the effects of the number of PKW units and of parapet walls on the PKW discharge efficiency. Results show that (i) the number of units does not affect the unit discharge per cycle, and (ii) parapet walls mounted on the inlet keys are not effective, whereas they increase the PKW efficiency if placed on the outlet keys.

RÉSUMÉ

Certains barrages existants nécessitent une réhabilitation des évacuateurs de crue, en adéquation avec la capacité requise. Pour ces projets, les déversoirs en touches de Piano (PKW) présentent une alternative intéressante. L'avantage des PKW sur les déversoirs labyrinthe standards est qu'ils peuvent être placés sur le couronnement de nombreux barrages, en raison d'une surface de base réduite. Le présent article étudie de manière systématique l'influence du nombre d'unités et l'effet d'une rehausse sur l'efficacité des PKWs. Les résultats montrent que (i) le nombre d'unités n'influence pas le débit spécifique par unité de longueur de crête et (ii) la rehausse installée sur l'alvéole d'entrée n'est pas efficace alors qu'elle améliore l'efficacité du PKW lorsqu'elle est placée sur l'alvéole de sortie.