Applied Analysis of Piano Key Weir (PKW) Structures as a Diversion Dam

J. Ahadian*, A.R. Afzalian

Department of Water Structure, Faculty of Water Science Engineering, Shahid Chamran University, Ahvaz, Iran.

ABSTRACT: In the present study, the hydraulic capability of piano key weir (PKW) was investigated utilizing the physical model. Because of decrease in water surface at dry seasons, these structure increases upstream head water. In addition, they have an appropriate discharge coefficient at the flood. To achieve the purposes of this research, two models of PKW were built with the ratio of height to a cycle width (P/Wu) equal to 1.33 (model 1) and 0.5 (model 2). The positive and negative slopes of parapet walls were considered with slopes 3, 5.5 and 8o rather than direction of flow. The results showed that model 2 has a more capability at the increased water surface in the low discharges. Moreover, model 1 has a suitable discharge coefficient at the higher discharge. Results obtained from analysis showed that H/R parameters have a significantly influence on the discharge coefficient when this weir is not submersible or there is a low head after fully submergence. The correlation of discharge coefficient equation after and before fully submergence of weir was 0.976 and 0.973, respectively.

1- Introduction

In normal condition, water surface elevation in rivers is lower than level of farmlands. Construction of diversion dams could be a means to increase water level in rivers for gravitational irrigation. In this case, a water intake with regulating gates could be used to convey the water from river to farmlands. During floods, required water would be conveyed to farmlands and extra flow would be released from the weir of diversion dam to the downstream river. Figure 1 illustrates a piano key weir (PKW) with its important hydraulic and structural elements. According to Figure 1, T is thickness of lateral crest, P is weir height, Pd is dam height, W0 is width of outlet key, Wi is width of inlet key, Bi is length of downstream slope, Bo is length of upstream slope, B is length of upstream-downstream weir, R is height of parapet walls, n is number of cycles and Wu is width of a cycle.
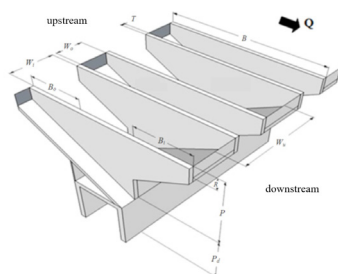

Figure 1. Three dimensional view of a piano key weir with geometric parameters

Lempérière et al (2011) performed first experiments on type A and B. They developed a dimensional analysis for investigation of models and introduced dimensionless parameter of L/W as an important factor on discharge coefficient of the weir [1, 2]. In type A, both upstream and downstream ramps exist, types B and C poses upstream and downstream ramps respectively and there is no ramp for type D. Reference [3] describes details and parameters of a piano key weir which includes 24 geometric parameters. Reference [4] investigates the effect of ration of inlet key width to outlet key width (W_i/W_o) and introduces 1.5 as the optimum value. Reference [11] analyses experimental results and expresses a relation for discharge coefficient which is function of W_i/W_o $(L-W)P_i/(WH)$, P_o/P_i and $(B_i+B_o)/B$. Reference performed the most comprehensive investigation on piano key weirs. In that research, velocity profile, pressure, water surface and Froude number from a physical model have been utilized to produce relations for estimation of discharge from inlet key, outlet key and lateral crest. References [7, 8] used computational fluid dynamic model, Flow 3-D and analyzed effect of clamp on hydrodynamics and discharge coefficient of piano key weirs. Reference [8] conducted experimental investigation to observe the effect of variable crest in two conditions of 0 and 10 degrees on discharge coefficient and rating curve, they have used general equation for discharge coefficient of weirs and found out 1.76 and 6.13 as discharge coefficient when crest is 0 and 10 degrees respectively. According to these descriptions and cost reduction for construction and operation, it is possible to utilize the geometry of piano key weirs.

Corresponding author, E–mail: Ja_ahadiyan@yahoo.com

2- Theory
2- 1- Dimensional analysis
It is possible to express discharge of piano key weirs with parapet wall in terms of the fallowing parameters:

$$f(w_i, w_o, w_u, B_i, B_o, L, L_{wu}, B, R,$$
$$P, P_{av}, w, Q, H, v, \rho, \sigma, \mu, g) = 0 \qquad (1)$$

In equation 1, W_i is inlet key width, W_0 is width of outlet keys, W_u is width of a cycle, B_i is length of inlet ramp, B_o is length of outlet ramp, L is crest length, $(L=n[w_i+w_0+2B])$, L_{wu} is crest length equivalent to one cycle, B is lateral crest length, R is height of parapet wall, P_{av} is average height of weir, $(P_{av}=P+R/2)$, W is flume width, Q is discharge, H is water head above weir, σ is surface tension, ρ is mass density, μ is dynamic viscosity and g is gravitational acceleration. If discharge coefficient could be considered in the context of equation 2, then using dimensional analysis and Buckingham π theorem dimensionless parameters would be classified as in equation 3. Parameter Ta/Tm is ratio of water level in models with parapet wall to reference models.

$$CD_{PKW} = \frac{Q}{WH^{1.5}\sqrt{2g}} \qquad (2)$$

$$f(CD_{PKW}, \frac{W_i}{W_o}, \frac{L}{W}, \frac{T_a}{T_m}, \frac{H}{L_{Wu}}, \frac{P}{W_u}, \frac{P_{av}}{W_u},$$
$$\frac{B_i}{B_o}, \frac{H}{P}, \frac{H}{R}, \frac{R}{P}, \frac{L}{B}, Fr, \text{Re}, We) = 0 \qquad (3)$$

Drawing CDw against parameters in equation 3 revealed a break in majority of curves; hence, for a better analysis data were classified into two categories (before and after submergence) and for each category an equation has developed. For estimating the performance of developed equations, in addition to R^2, error functions NRMSE and WQD have used.

3- Developed equations for discharge coefficient
3- 1- Before submergence
Studies of Leite Ribeiro et al. (2012) for estimation of discharge over piano key weirs and experimental results of Machiels et al. (2012) showed that discharge over a piano key weir could be related to discharge over sharp crested weirs via (L-W)/H parameter. In this research, before submergence, effective length of weir changes as a result of change in water level therefore the aforementioned parameter could be considered. In sloped model, crest length is varied as a result of variation of water level and L_{eff} should be used instead of L. In order to calculate L_{eff} fallowing equations could be used.

$$L_{eff} = nL_{Wu} \qquad (4)$$

$$L_w = H.\csc(\alpha) \qquad (5)$$

Analysis showed that there is no strong correlation between discharge coefficient and $(L_{eff}-W)/H$ for sloped weirs. Also researchers found out that a greater correlation could be achieved by relating the discharge coefficient to α and β parameters which are defined as follow or even their product $\gamma = \alpha \times \beta$.

$$\alpha = 1 + \left(\frac{H}{R}\right)^{0.25} \qquad (6)$$

$$\beta = \left(\frac{(L_{eff}-W)P_{av}}{HW_u}\right)^{0.07} \qquad (7)$$

$$C_{DW} = 1.4\gamma^2 - 5.37\gamma + 5.25 \qquad (8)$$

Average error for equation 8 is 15 percent.

3- 2- After submergence
Many types of equations have fitted to experimental data for estimation of discharge coefficient in submerged condition and finally equation 9 found to have best precision.

$$C_{DW} = 3.51\left(\exp(\frac{H}{P})\right)^{\frac{R}{B}} - 3.49\left(\exp(\frac{R}{P})\right)^{\frac{R}{B}}$$
$$+ \left(\frac{R}{B} \cdot \frac{H}{L_{Wu}}\right)^{-0.18} - \left(\frac{P_{av}}{W_u}\right)^{-0.57} - 0.4 \qquad (9)$$
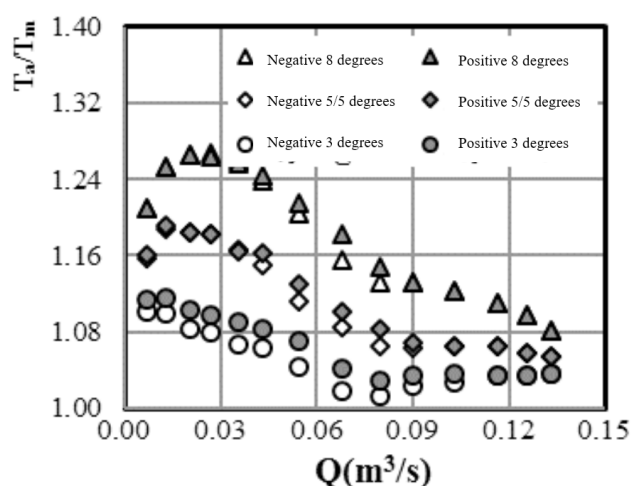
Average error for equation 9 is about 10%.

4- Potential for water diversion and water release
Figure 2 illustrates the ratio of water level of models with sloped parapet (Ta) wall to reference models (Tm).
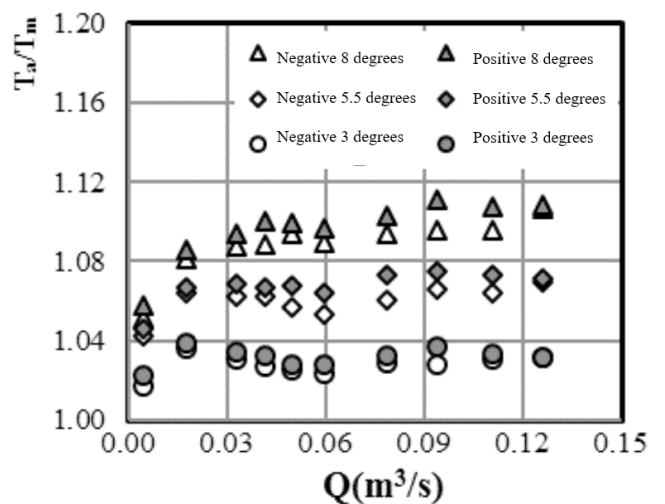
(a) Model 1

(b) Model 2

Figure 2. Changing of water level on PKW with sloped parapet wall

In low discharges, due to reduction of effective lateral length of a sloped weir, upstream water level would be higher than that of a reference model. But in higher discharges, due to increase of lateral crest length in sloped weirs water surface elevation poses a decreasing trend in comparison with reference model. In very high discharges, the efficiency of weirs with sloped parapet walls is lower than reference weirs and it could be attributed to interference of lateral water napes. Generally it could be concluded that in low discharges sloped walls provide larger water level in comparison with reference weir, while with increasing the discharge, their flow release efficiency decreases. Comparison of model 1 and 2 in Figure 2 shows that in model 2, water surface increase in low discharges are more than that of same slopes for model 1. In the other hand in high discharges relative reduction of water surface elevation makes the purpose of this research more prominent. For example Figure 2for slope of +8 degrees, in low discharges, represents a water surface increase of 10% more than reference model, but this slope for model 2 (Figure 2), in low discharges, represent more than of 26% increase of water surface elevation.

5- Conclusion

General qualitative and quantitative results of the present study are summarized as the fallowing:

1- For application of piano key weirs (PKW) with sloped parapet walls as constant weir or diversion dam, convenient range appears to be $0.5 < P/W_u < 1.33$. Because in this range, the weir has a good potential to increase water surface elevation in low discharges and has a good capacity to release water at high discharges. In this condition, the water surface elevation of sloped weirs and normal weirs are same in high discharges.

2- Analysis of results reveals that before submergence, when the effect of surface tension is great, parameter H/R is a very effective parameter on discharge coefficient.

3- Formulae 8 and 9 are developed to estimate discharge coefficient of piano key weirs with sloped parapet walls in submerged and non-submerged condition.

References

[1] Lempérière, F. and Ouamane, A., "The Piano Keys weir: a new cost-effective solution for spillways", International Journal of Hydropower and Dams, Volume 10, Issue 5, pp 144-149, 2003.

[2] Lempérière, F., Vigny, J.P. and Ouamane, A., "General comments on Labyrinth and Piano Key Weirs The past and present", Proc. Intl. Conf. Labyrinth and Piano Key Weirs, Liège B, 17-24. CRC Press, Boca Raton FL, 2011.

[3] Pralong, J., Vermeulen, J., Blancher, B., Laugier, F., Erpicum, S., Machiels, O., Pirotton, M., Boillat, J.L., Leite Ribeiro, M. and Schleiss, A.J., "A naming convention for the piano key weirs geometrical parameters", Proc. Intl. Conf. Labyrinth and Piano Key Weirs, Liège B, 271-278. CRC Press, Boca Raton FL, 2012.

[4] Anderson, R.M. and Tullis, B., "Influence of Piano Key Weir geometry on discharge", Proc. Intl. Conf. Labyrinth and Piano Key Weirs, Liège B, pp 75-80, CRC Press, Boca Raton FL, 2011.

[5] Leite Ribeiro, M., Pfister, M., Schleiss, A.J. and Boillat, J.L. "Hydraulic design of A-type Piano Key Weirs". Journal of Hydraulic Research, Volume 50, Issue 4, pp 400-408, 2012.

[6] Safarzadeh, A. and Nourozi, B. "The numerical study of parapet wall on hydraulically performance of PKW", International Conference on water resource management, Tehran, Iran, 2013.

[7] Safarzadeh, A. and Nourozi, B. "3D hydrodynamics Comparison of PKW and Labyrinth weirs", International Conference on civil, architected and urban development, Tabriz, Iran, 2012.

[8] Karimi Chartaghi, M. and Nazari, S. "Experimental investigation on discharge coefficient in PKW with variable crest", 8th national congress on civil engineering, Babol, Iran, 2014.

[9] Pralong, J., Vermeulen, J., Blancher, B., Laugier, F., Erpicum, S., Machiels, O., Pirotton, M., Boillat, J.L., Leite Ribeiro, M. and Schleiss, A.J., "A naming convention for the piano key weirs geometrical parameters", Proc. Intl. Conf. Labyrinth and Piano Key Weirs, Liège B, 271-278.

CRC Press, Boca Raton FL, 2012.

[10] Leite Ribeiro, M., Pfister, M., Schleiss, A.J. and Boillat, J.L. "Hydraulic design of A-type Piano Key Weirs". Journal of Hydraulic Research, Volume 50, Issue 4, pp 400-408, 2012.

[11] Karimi Chartaghi, M. and Nazari, S. "Experimental investigation on discharge coefficient in PKW with variable crest", 8th national congress on civil engineering, Babol, Iran, 2014.