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Evaluation and Analysis of Crest Coefficient for Labyrinth Weir

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Abstract: The capacity of an existing spillway can be increased by lengthening the spillway crest, or increasing the discharge coefficient or operating head, or any combination of these approaches. Constructing a labyrinth weir in an existing spillway is an example of an effective way to increases the spillway crest length and the corresponding discharge capacity for the same operating head. Thus, labyrinth weir are well suited to the sites where increasing the spillway width and maximum reservoir water surface elevation would be difficult, yet larger discharge are needed. This type of weir consists of series of slender walls having a repeating shape in plan, usually triangular or trapezoidal with vertical upstream faces and steeply slopping downstream faces. Over the past few decades, labyrinth spillways have been constructed throughout the world. Definite guidelines and theoretical procedures pertaining to hydraulic design of this type of weir not completely established. There are many factors such as head to crest height ratio, vertical aspect ratio, side wall angle, apex width and approach and conveyance channel conditions that influence the capacity of weir and hence the hydraulic design of labyrinth weir. In this paper extensive physical modeling of the labyrinth spillway, primarily flume studies, has been performed, resulting in the development of Lux and Tullis methods are compared for a given labyrinth spillway. Further testing to define labyrinth hydraulic behaviour for this lower vertical aspect ratio (w/p) is recommended.

Key words: Labyrinth weir · Spillway · Floods hydraulics structure · Hydraulics

INTRODUCTION

A labyrinth spillway is an overflow weir folded in plan view to provide a longer total effective length for a given overall spillway width (Figure 1) Therefore, labyrinth spillways may provide a higher discharge capacity than that of a straight overflow weir, for a given total upstream head and total width. Labyrinth spillway can be economical solution for increasing capacity as they provide increased unit discharge over conventional weirs for a given head.The use of labyrinth spillway in the world is done from the last 25years. It is likely that this increase is partly due to development of these method by Lux [1] and Tullis *et al*. [2], Prior to the development of these methods, Taylor [3] extensively studied the behaviour of the labyrinth weirs and presented the hydraulic behaviour as it compares to that of sharp-crested weir. Additional work by Darvas [4] utilised the results from physical model studies to expand on the theory and developed a family of curves to evaluate spillway performance. Lux [1] assessed the hydraulic performance of labyrinth weirs using data obtained from flume studies and specific models. He introduced another discharge coefficient based on the total upstream head. Tullis *et al*. [2] conducted a series of experiments with different labyrinth angle in the range of 6º to 18º and proposed the expressions for coefficient of discharge for labyrinth weir. These values of coefficient of discharge can be used in the linear weir equation and resulting labyrinth weir discharge can be obtained.Falvey [5] summaries the Lux and Tullis method, which were empirically developed from physical model studies. This paper extensive physical modeling of the labyrinth spillway, primarily flume studies, has been performed, resulting in the development of Lux and Tullis methods are compared for a given labyrinth spillway.

Theoretical Considerations for Flow over of Labyrinth Weir: A labyrinth spillway is an overflow weir folded in plan view to provide a longer total effective length for a given overall spillway width (Figure 1). It is relatively slender walls having a respective plan form,

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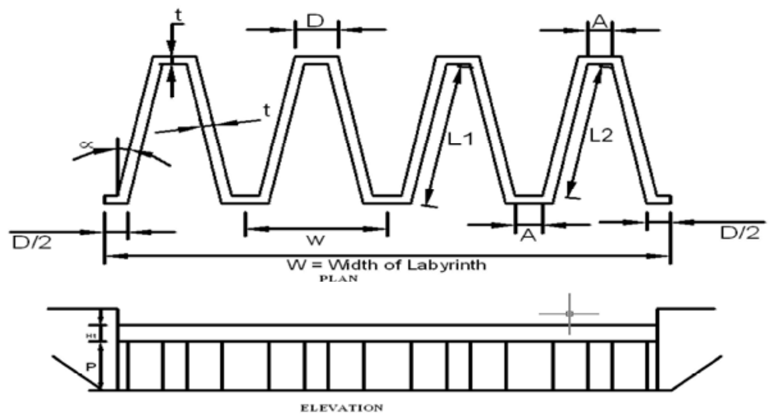

Fig. 1: Layout and details of labyrinth weir

shaped generally triangular or trapezoidal with a vertical upstream face. The capacity of labyrinth weir is a function of total head, the effective crest length and the crest coefficient. The crest coefficient depends on the total head, weir height, thickness, crest shape apex configuration and the angle of the side wall. When the weir is placed at an acute angle to the flow, the flow becomes three dimensional. For the straight weirs, all the streamlines are perpendicular to the crest and two-dimensional. But for inclined weir, like a labyrinth weir, the streamlines under the nappe are almost perpendicular to the crest, whereas at the free water surface the streamline are directed in the downstream direction. The flow over the labyrinth weir is complicated further by the interference of jet at the upstream apex of the labyrinth. At high flows, the jets from adjacent crests strike each other. This creates a nappe that is not aerated and can decrease the discharge coefficient of the weir. The degree of impact increases as the angle between the crests decreases and as the flow depth over it increases. As a result, for most labyrinth weirs, the underside of the nappe is aerated only for low flow depths. The interference of the jet from adjacent crest means that labyrinth weirs become less and less effective as the reservoir level rises. At some depth, the flow over a labyrinth weir is almost the same as the flow over a straight.

Lux [1]: Developed the hydraulic performance of Labyrinth weirs from the data obtained from flume studies and site specific models. He used the combination of dimensional analysis and experimentation to develop an equation for the discharge of the labyrinth weir. Lux also defined the discharge coefficient for triangular and trapezoidal planforms with the sharp-crested and quarter-round labyrinth weir. The equation that Lux developed for the discharge function as

$$Q = Cw\left[\frac{\frac{w_c}{p}}{\frac{w_c}{p}+k}\right]w_c H\sqrt{gH}$$

Where

Q = Discharge of one cycle

Cw = Discharge coefficient

w/p = Vertical aspect ratio

H = Total head

K = Constant for triangular and trapezoidal forms in plan, K has a value of 0.18 and 0.10 respectively.

The total discharge of labyrinth weirs can determine by multiplying Q by the number of cycle n.

Tullis *et al.* [2]: Defined a coefficient that used the total upstream head on the weir. Presented the crest coefficient for labyrinth weir with quarter round crest shape. The discharge over labyrinth weir can be expressed as.

$$Q = C_L.\frac{2}{3}\sqrt{2g}.LHt^{3/2} \tag{1}$$

Where

Q = Discharge over weir,

CL = Crest coefficient per unit length of the labyrinth weir,

L = N*($2L_2$+2A)= Effective length of labyrinth weir,

Ht = Total head = $(h+\frac{v^2}{2g})$,

h = Pizeometric head over the weir,

g = Gravitational acceleration constant.

However, for design purpose, it is more convenient to express discharge over labyrinth weir in the form of equation,as,

Table 1: Details of Labyrinth Weir Geometry of Various Dams

S.No.	Hyrum Dam (USA)	Serno Dam (Algeria)	South heart Dam (Canada)	Dog River Project(Georgia)
Weir height(P)	3.66m	2.55m	4m	7.6m
Cycle Width (w)	9.15m	15m	11.75m	9.22m
Vertical Aspect Ratio (w/p)	2.5	6	2.94	1.2
Apex width (2a)	1.22m	3m	1.22	1.22
Number of cycle (n)	2	1	2	8
Length Magnification (L/W)	4.95	4	4.95	4
Side wall Angle (α)	9.1º	9.59º	9.1º	9.1º

$$Q = Cw.\frac{2}{3}\sqrt{2g}.WHt^{3/2} \tag{2}$$

Where

Cw = Crest coefficient per unit width of the labyrinth weir

W = Width of the labyrinth weir.

Comparative Analysis of Design Parameters by Application of Lux and Tullis Methods: The Lux and Tullis methods were empirically for design of labyrinth spillway using a wide range of weir geometries. For both methods, quarter-round crest shape is recommended. Tullis recommends a w/p ratio of 3 to 4 while the Lux method is considered appropriate for w/p ratios greater than 2. Both methods suggest a maximum Ht/P of about 0.7. However, the equation of Tullis applicable up to Ht/P of 0.9. To compare these two method, discharge rating curve were developed for a given labyrinth weir for Hyrum dam (USA), Serno Dam (Algeria), South heart Dam (Canada) and Dog River Project (Georgia) labyrinth spillway geometry was selected for this comparison, as shown in Table 1. The comparative study on crest coefficient for trapezoidal labyrinth weirs is based on the experimental equation of Lux [1] and Tullis *et al* [2]). It should be noted that Lux [1] and Tullis *et al* [2] studied quarter round crested labyrinth weirs. The crest coefficient for Ht/P value 0.05 to 0.5 shown in Figure-2, 3, 4, 5. The average percentages variation for discharge coefficient observed for Hyrum dam 5%, for Serno dam 4.3%, for South heart dam 2.6% and Dog river project 4.7%

Vertical Aspect Ratio: Vertical aspect ratio (w/p) also influences the hydraulic efficiency of the labyrinth It is recommended that the adopted value of the vertical ratio should not be less than 2 in the case of trapezoidal plan from weir and not less than 2.5 in the case triangular plan from weirs. Lux and Tullis method recommend a minimum aspect ratio, or w/p of 2 to 3. Falvey [5] states that the studies of Hay and Taylor [3] showed the aspect ratio does not have a significant effect if it is greater than 2; however, the application of either the Lux or Tullis method indicate that hydraulic performance does improve with increasing weir height (p) and corresponding decreases in

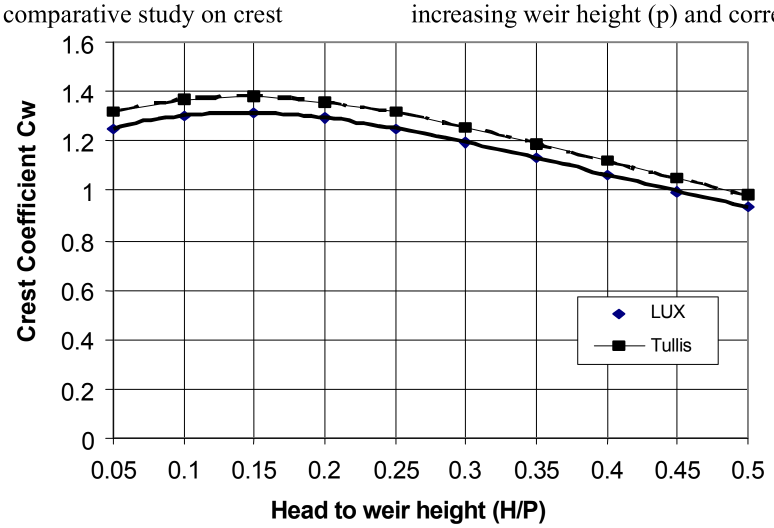

Fig. 2: Comparision Chart for Discharge coefficient (Hyram Dam)

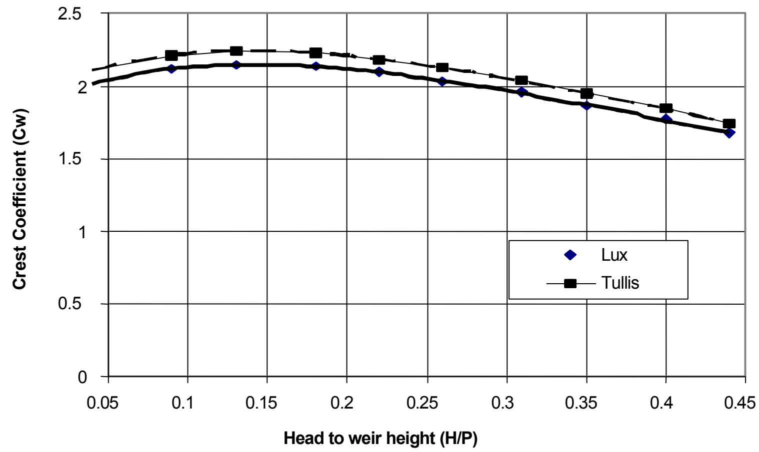

Fig. 3: Comparision Chart for Discharge Coefficient (Serno Dam)

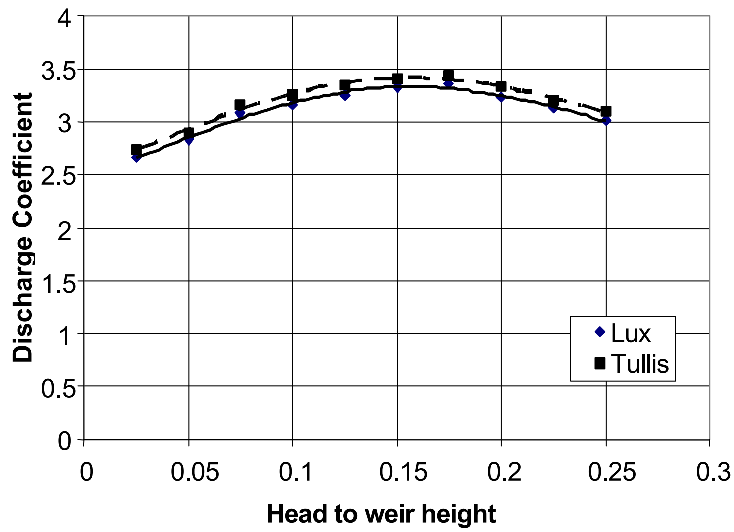

Fig. 4: Comparision Chart for Discharge Coeffiecient (South Heart Dam)

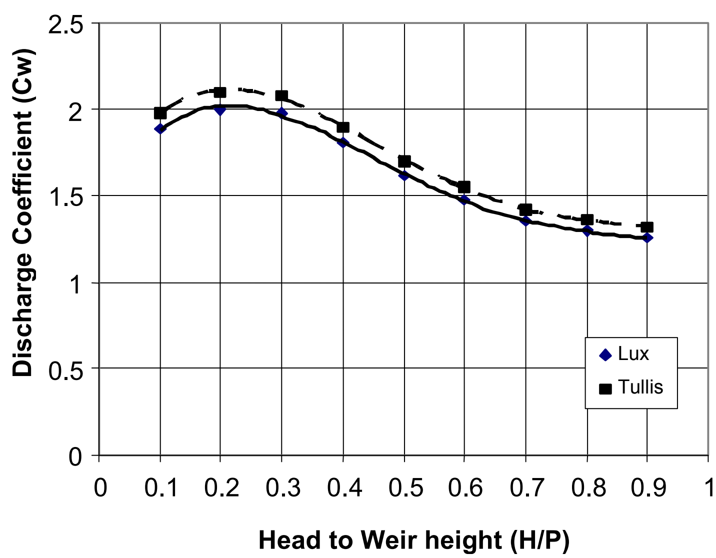

Fig. 5: Comparision Chart for Discharge Coeffiecient (Dog River Dam)

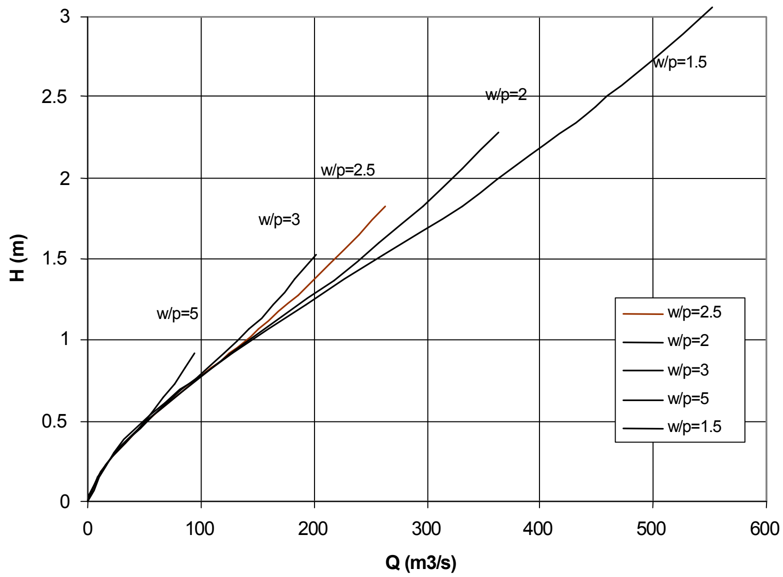

Fig. 6: Effect of the w/p ratio

the aspect ratio for a given plan geometry. To illustrate this discharge rating curve was developed using the Lux method (Hyrum geometry) shown in Figure-6 indicating that weir height for given plan geometry i.e decreasing w/p results in the greater discharge for the given head, especially for higher heads. It should be noted that the application of the aspect ratio of 1.5 using the Lux method is not considered appropriate since it is below the recommended value of 2. The data is presented in Figure-6 for comparisons only. Reducing the aspect ratio to less than 2 may provide benefit to the project without significantly affecting performance.

CONCLUSION

The labyrinth weir represents an effective solution for increase in the storage capacity. Labyrinth weir shall find greater application due to its inherent advantages in connection with flow magnification and structural stability Labyrinth weir can provide an economical flood discharging structure. Both these (Lux and Tullis methods), yield similar results for the evaluation of labyrinth spillway and the hydraulic performance of labyrinth weir is constant up to design head (H/p) of 0.2 there after the discharge vary approximately 10% less than the Tullis method. The aspect ratio (w/p) has effect on performance of labyrinth weir. Figure-6 indicates that hydraulic performance of labyrinth weir improves for w/p ratio less than 2. The comparative analysis of discharge coefficient per unit width shows that the maximum difference between the values of crest coefficient is 5%.

Notations

Ht = Total upstream head on weir
P = Weir height
W = Total width of Labyrinth weir
w = Width of one cycle of labyrinth
A = Inside apex width
l = length of one cycle ($2L_1$+A+D)
L = Effective length of labyrinth =N ($2L_2$+2A)
t = wall thickness
α = Angle of side edge or labyrinth angle
N = Number of cycle
B = Length of labyrinth apron

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