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Determination of Crest Coefficient for Flow over Trapezoidal Labyrinth Weir

[1]B.V. Khode, [2]A.R. Tembhurkar, [3]P.D. Porey and [4]R.N. Ingle

[1]Research Scholar, Visvesvaraya National Institute of Technology, Nagpur, India
[2]Associate Professor, Visvesvaraya National Institute of Technology, Nagpur, India
[3]Director, S.V. National Institute of Technology, Surat, India
[4]Retd. Professor, Visvesvaraya National Institute of Technology, Nagpur, India

Abstract: Use of Labyrinth spillway is particularly suitable where the spillway width and upstream water surface are limited and larger discharging capacities are required. It is an effective method to increase the spillway crest length without an associated increase in structure width. It consists of a series of relatively slender walls having a respective plan form, shaped generally triangular or trapezoidal with a vertical upstream face. Continued efforts are being focused towards development of design curves with different shapes and configurations. The research presented here mainly aims at determining the crest coefficient for flow-over trapezoidal labyrinth weir by conducting experimentations at wide range of values of side wall angles (α) from 6° to 30°.

Key words: Labyrinth weir · Spillway · Hydraulics structure · Hydraulic design

INTRODUCTION

Labyrinth weir have the distinguish characteristics of a relatively high discharge for a given head, relative to linear weir of the same width. Labyrinth spillway can be economical solution for increasing unit discharge over conventional weirs for a given head. It is particularly suited for use as a service or emergency spillway at a reservoir site where large discharge is to be handled at relative narrower waterway. An extensive investigation on the influence of geometric and hydraulic parameters on the hydraulic behaviour of labyrinth weirs, particularly on the discharge capacity, has been done by several researchers. Taylor [1] extensively studied the behavior of labyrinth weir and presented the hydraulic performance as it compares to that of sharp-crested weir. Hay and Taylor [2] followed up on Taylor's work and developed design criteria for labyrinth weirs. Additional work by Darvas [3] utilized the results from physical model studies to expand on the theory and developed a family of curves to evaluate spillway performance. Extensive physical model studies were performed by Houston [6-7] to evaluate various labyrinth geometries and approach conditions. U.S. Bureau of Reclamation (USBR) tested model of labyrinth spillway for Ute Dam and Hyrum Dam They found that the discrepancy between their result and those of Hay and Taylor [2] were due to difference in head definition. Megalhaes [8] developed curves similar to that of Darvas [3] except their curves are for a nappe or ogee shaped crest. Lux [4-5] studied the hydraulic performance of Labyrinth weirs using dimensional analysis and developed an equation for the discharge of the labyrinth weir from the data obtained from flume studies. Tullis *et al.* [9] carried out extensive experimental work on performance of the labyrinth weir and presented crest coefficient curves in simplified way as compared to previous investigators. They proposed a method for designing a labyrinth weir by using the basic equation used for linear weir which would also be applicable to labyrinth weir with modification in coefficient of discharge. Tullis *et al.* [10] also conducted test to optimize the performance of 7° and 8° labyrinth weirs at low heads for different crest shape. Further, Tullis et. al. [11] conducted experiments to find effect of submerged condition and developed head-discharge relationship. Experimental data generated by Tullis is limited for side wall angles (α) between 6° to18° and they extrapolated their experimental data for weir side wall angles up to 35°. This extrapolated value of crest coefficient obtained from design curves has its own limitation in use for designing. Moreover, in practice α value may lie in the range of 18° to 30°. Therefore, there is a need to undertake research for values of α greater than 18° so as to present a complete data range which can be used for the design of labyrinth weir. As such the outcome of research work will be highly beneficial due to its use in various irrigation and water resources projects. In the present research, experiments are conducted to determine crest coefficients to develop design curves for range of 6° to 30°. Design curves are obtained from the experimentation data and

Corresponding Author: B.V. Khode, Research Scholar, Visvesvaraya National Institute of Technology, Nagpur, India.

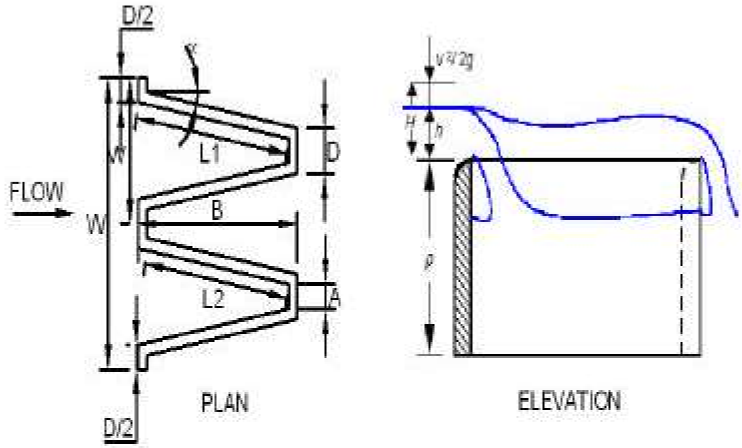

Fig. 1: Layout and Details of Labyrinth Weir

relation between value of crest coefficient and the dimensionless parameters (Ht/P) is presented which can be used as guidelines while designing a labyrinth weir.

Mathematical Equation for 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 (Fig. 1). It is relatively slender walls having a respective plan form, shaped generally triangular or trapezoidal, with a vertical upstream face. The flow over labyrinth weir is three dimensional and does not readily fit into mathematical description and hence the discharge function is found through experimental studies and analysis. 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 angle of side wall. To simplify the analysis, the effect of viscosity and surface tension could be neglected by selecting model and velocity of sufficient magnitude. With this assumption only important parameter is the gravitational acceleration which is the ratio of specific weight and density of fluid. For the practical reasons, it is more suitable to represent the crest coefficient as non- dimensional parameter. The crest co-efficient is dependent on the same variable influencing a linear weir plus the configuration of the labyrinth at its apex and the angle of the labyrinth.

The discharge over labyrinth weir can be expressed as

$$Q = Cw\ 2/3\ \sqrt{2g}\ W\ Ht^{3/2} \tag{1}$$

Where,

Q = Discharge over weir,

C_L = 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

Experimental Setup: The experimental set-up mainly consists of sump, pumping system, initial discharge tank, rectangular flume, discharge measuring unit and labyrinth weir. The schematic arrangement of the experimental set up is shown in Fig. 2. The water used for experimentation was pumped from a sump (2.5x2.5x2.5m) through 10H.P pump and main pipe line of 150mm diameter into initial discharge tank of size 2.5 x 1.0x 0.65.m having triangular notch on one side to measure initial discharge. A precisions point gauge was used to determine the elevation of the weir crest and obtained the water surface elevation of approaching flow. The point gauge had a vernier scale that was marked in 0.1mm increments. The kinetic energy of the flow is reduced by a steel grate with many 3/16-inch diameter holes was placed across the head of the flume. Further reduction in splashing was done by keeping wooden grate floating to obtain more uniform water surface entering the experimentation flume. The inflow was regulated to the desired flow by operating the valve. The water is then allow to 0.5m wide x 0.5m deep x 3.4m long rectangular flume having an arrangement to place various labyrinth weir of different geometries. A traversing point gauge having accuracy of 1mm was mounted on roller carriage track running the length of the flume. To ensure correct piezometric head measurement and account for deviations in the correction factor was added to the point gauge reading which was

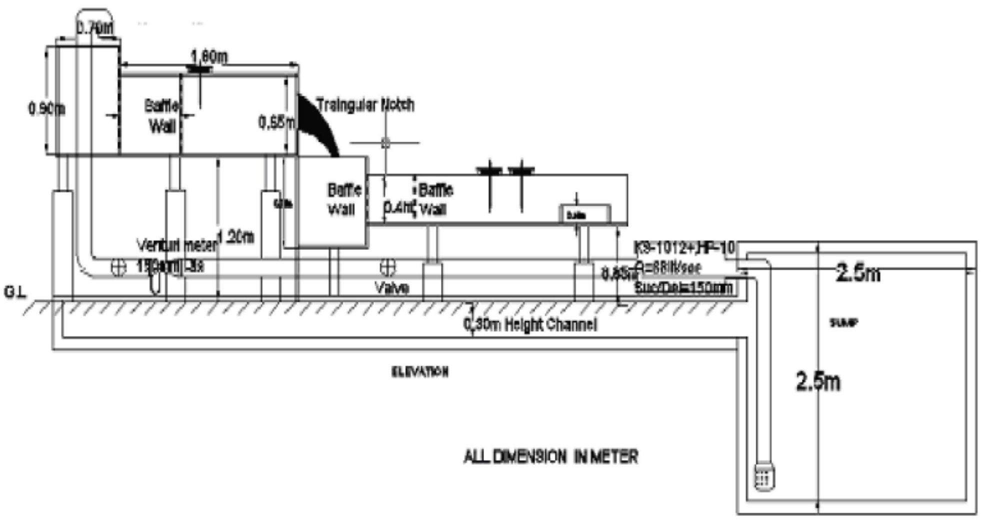

Fig. 2: Schematic Arrangement of Labyrinth Weir

predetermined by using a static water surface in the flume. The gauging station was located such that it avoids the area of water surface draw-down, yet closed enough for the energy loss between the gauging station and structure to be negligible. It was located between four to five times the maximum total head over the weir upstream from the face of the weir. The experimentation flume is mounted on steel super structure with jack assembly to control the slope. The dimensions of quarter round crest shape labyrinth weir having different geometrics based on varying side wall angle of 6°,8 °,10 °,16 °,21 °,26 ° and30 ° used during experimentation. Each labyrinth weir was approximately 0.15m in height, fabricated using 15mm thick acrylic sheet material and having two complete labyrinth weir cycles. Each labyrinth weir was tested at a height P equal to 0.15m. All the weirs were installed at the position of the flume to provide an unrestricted supply of air under the nappe.

Experimental Procedure: The experimentation was started by calibrating the triangular notch. Each labyrinth weir was then tested with a starting inflow 0.004m^3/s, which was gradually increased at each increment of flow so as to obtain increment of Ht/P ratio of 0.05. The testing was done for each weir for a range of flow to cover Ht/P ratio from 0.1 to 0.7. The flow rates were measured using calibrated triangular notch. The total head over the weir was taken as the difference in the water surface and the crest plus the velocity head and was measured at 4 to 5 times the maximum total head over the weir upstream from the face of the weir. For each test run, the flow in channels was allowed to become stable and the flow rate readings were repeated to obtain accurate reading at steady conditions. The limiting condition and the ranges of variable covered in this study for Labyrinth weir are as follows.

- 0.1< Ht/P < 0.7
- Plan form- Trapezoidal
- Crest Shape - 1/4 round
- α= 6°,8°,10°,16°,21°,26°,30° and Linear
- Height of weir (P) =0.15m

RESULTS AND DISCUSSIONS

Experimentation are carried out on different quarter round trapezoidal labyrinth weir with side wall angle 6° to 30°. For each model of labyrinth weir the discharge is adjusted at different value in the range 0.004 m^3/sec to 0.032m^3/sec and head is measured for each value of discharge. From these observations the value of crest coefficient is calculated based on equation (1) and variation of C_L with Ht/P is plotted in a graph as shown in Fig. 3. To represent the data in the of equation form, regression analysis is carried out for the observed data for each model separately. It is found that 4th degree polynomial fits well to obtained relation between C_L and Ht/P therefore crest coefficient ($C_{L)}$ is expressed

$$C_L = A_O + A_1E + A_2E^2 + A_3E^3 + A_4E^4 \qquad (2)$$

In which $E = \frac{Ht}{P}$

Table 1: Crest Coefficient for Effective Length of Weir (C_L)

Labyrinth Angle	A_0	A_1	A_2	A_3	A_4	R^2	Limitation
6	0.137	2.727	-10.458	14.973	-7.558	0.9872	E < 0.70
8	0.166	2.601	-9.334	13.004	-6.582	0.9953	
10	0.201	2.264	-7.192	8.556	-3.586	0.9972	
16	0.282	1.579	-4.198	4.225	-1.497	0.9919	
21	0.294	1.504	-3.350	2.686	-0.655	0.9617	
25	0.296	1.835	-4.649	5.018	-2.046	0.9765	
30	0.334	1.715	-4.113	4.166	-1.578	0.9205	
Linear	0.370	1.375	-2.219	1.137	--	0.8386	

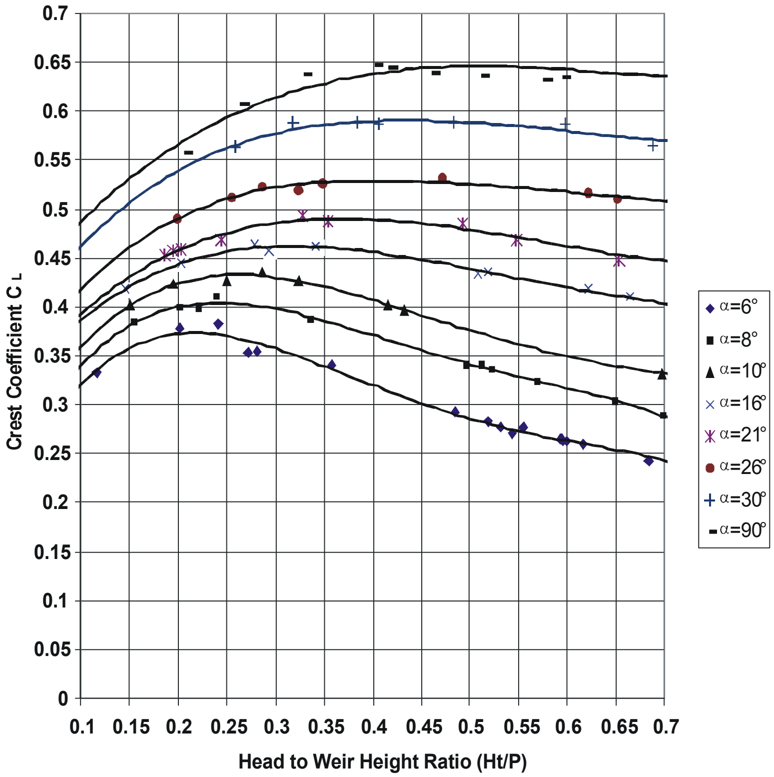

Fig. 3: Variation of Crest Coefficient (C_L) with Head to Weir Height (Ht/p) for different Side Wall Angle (6° to 30°) and Linear

The values of coefficients A_0 to A_4 along with R^2 are shown in Table 1. Equation 2 is valid for the range for 0.1< Ht/P <0.7. The relationship of maximum C_L with respect to α is obtained and represent in Fig. 3. It can be seen from Fig. 3, crest coefficient (C_L) decreases as the side angle reduces, the probably due to the effect of three dimensional flow in labyrinth weir. It can be observed that there is a maximum value for crest coefficient in each of the curves at the initial stage, followed by the long recession limb. It suggested that while designing the layout of the labyrinth weir, the Crest Coefficient (C_L) should lie close to the peak value of the curve. The relationship between $C_L max$ is the function of α and Ht/P and is graphically represented in Fig. 4. The relationship obtained by regression analysis for the maximum value of crest coefficient C_L in terms of side wall angle and Ht/P is given by

$$C_l max = 0.2329\,(\alpha)^{0.2839} \quad (3)$$

With $R^2 = 0.995$

and Corresponding Value of Ht/P is given by

$$Ht/P = 0.0997(\alpha)^{0.4268} \quad (4)$$

With $R^2 = 0.996$

Table 2: Comparison Of C_l Prototype Dam With C_l Estimated From Eq.2

Location	Side wall) Angle (α)	Weir Height (m)	Total Head (m)	Head to Weir height Ratio (Ht/P)	Number of Cycles	Total Crest Length (m)	Prototype dam Flow` (m3/sec)	C_L Prototype Dam	C_L Estimated From Eq.3	% Diff between C_L Prototype Dam and C_L Estimated From Eq.3
Avon Dam, Australia.	27.5	3.05	2.16	0.72	10	265	1420	0.572	0.547	-4.37
Bartletts Ferry, U.S.A.	14.5	3.43	2.44	0.64	20.5	1441	6796	0.419	0.407	-2.86
Boardman, USA.	19.44	3.53 (Avg)	1.8	0.50	2	109.2	387	0.497	0.491	-1.21
Carty, USA.	19.40	2.76	1.8	0.50	2	109.2	387	0.497	0.490	-1.41
Dungo, Angola.	15.2	4.3	2.4	0.56	4	115.5	576	0.454	0.434	-4.41
Hyrum, USA.	9.14	3.66	1.82	0.50	2	91.44	262	0.395	0.374	-5.31
Navet, Trinidad	23.6	3.05	1.68	0.55	10	137	481	0.546	0.521	-4.58
Ute Dam, U.S.A.	12.15	9.14	5.80	0.63	14	1024	15574	0.369	0.377	+2.17

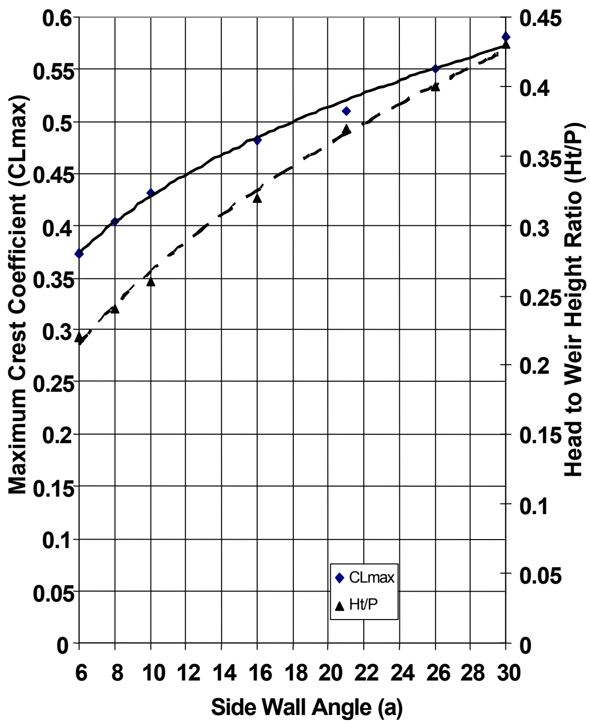

Fig. 4: Maximum Value of Crest Coefficient ($C_L$max) with Head to Weir Height Ratio (Ht/p) for Side wall angle (6° to 30°)

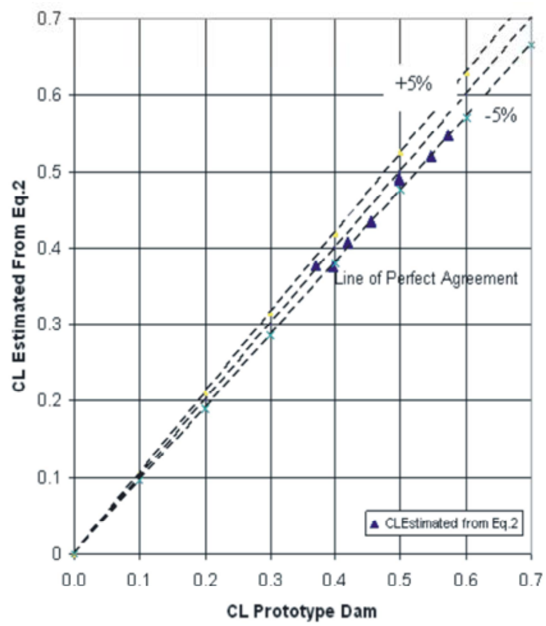

Fig. 5: Comparison of C_L Prototype dam with C_L Estimated from Eq.2

Validation of Data: The comparison between the C_L prototype dams is carried out with C_L estimated from Eq.2. Eight prototype dams having labyrinth weir have been taken up for validation. Table.2 shows the comparison of C_L prototype dam, C_L estimated from Eq.2 The estimated value of crest coefficient have been calculated using regression equation 3, The intermediate values of crest coefficients have been computed by interpolating crest coefficients of adjacent side wall angles. Table 2 and Fig.5 shows that the C_L of prototype dam and C_L estimated from eq.2 lie between ± 5%.

CONCLUSION

Labyrinth weir finds greater application due to its inherent advantages in connection with flow magnification and structural stability. It can provide an economical flood discharging structure. The design is particularly suited for use at sites where the head is limited or the spillway width is restricted by the topography. The labyrinth weir represents an effective solution for increase in the storage capacity. The values for crest coefficient can be suitably obtained from the design curves and the regression equation generated through this study for α between 6° to 30°. Based on experimental data obtained from flume studies on labyrinth weirs of side wall angles 6,8,10,18 21 26,30 degree and upstream quarter round crest and linear weir of quarter round crest on upstream face, the following conclusions are drawn.

- The coefficient of discharge for effective length of weir C_L, initially increases with head reaching a maximum value and then decreases gradually.
- The coefficient of discharge C_L is minimum for side wall angle of 6 degree and increases with increase in side wall angle approaching the value of linear weir.
- Crest coefficient of Prototype dam and estimated Crest Coefficient from Eq.2 lie between ± 5%.
- The layouts of labyrinth weir should be normally designed for maximum value of $C_L$max and the design curve developed from this present experimental study would help the designer to design Labyrinth weir.

Notations:

Ht = Total upstream head on weir
P = Weir height
W = Total width of Labyrinth weir
W = Width of one cycle of labyrinth
C_L = Crest Coefficient for effective length of weir
$C_l$max = Maximum Value of Crest Coefficient
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
L1 = Actual length of a single leg of the labyrinth weir
L2 = Effective length of a leg of the labyrinth weir.

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