International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor (2018): 7.426

Experimental Investigation of Discharge Capacity of Labyrinth Weirs

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Abstract: ***A labyrinth weir is a structure designed to convey large flows at low heads by increasing the effective length of the weir crest with respect to the channel breadth. The crest shape is one of the most important factors which affect the discharge capacity for labyrinth weirs. It is found that the labyrinth weirs are hydraulically more efficient than the other normal weirs for higher discharge. The discharge over the labyrinth weir is same as an equivalent length straight weir for low head, whereas, with increase in head over the weir, the coefficient of discharge continues to decrease due to interference of jet and the weir capacity ultimately equal to that of the linear weir having crest length equal to the channel width.***

Keywords: Weirs, Labyrinth Weir

1. Introduction

Water management and conveyance are a critical component of human civilization. As infrastructure ages and development continues, the need for hydraulic structures increases.

A weir is a simple device that has been used for centuries to regulate discharge and upstream water depths and to measure flow rates. Weirs have been implemented in streams, canals, rivers, ponds, and reservoirs. There are many weir geometries and one of them is a labyrinth weir which is a linear weir that is folded in plan-view. This is done to increase the length of the weir relative to the channel or spillway width, thereby increasing the flow capacity of the structure over a linear weir for a given driving head. There are three general classifications based upon cycle shape: triangular, trapezoidal, and rectangular. Labyrinth weirs have been of interest to engineers and researchers for many years because of their hydraulic behavior. A labyrinth weir provides an increase in crest length for a given channel width, thereby increasing flow capacity for a given upstream water elevation. Therefore, labyrinth weirs maintain a more constant upstream depth and require less free board than linear weirs. A labyrinth spillway can satisfy increased flood routing requirements and increase reservoir storage under base flow conditions, relative to a linear weir structure, such as an ogee-crest spillway. In addition to flow control structures, labyrinth weirs have also been found to be effective flow aeration control structures, energy dissipaters and drop structures.

The rectangular weirs are particularly apt for discharge retention up to the weir crest, generating high discharge during floods. The weir is a fundamental hydraulic structure by which discharge can be measured, rivers are made navigable or flooding is prevented particularly if gates are added. When the overflow zone is often laterally restricted the overflow depths increases causing submergence on the upstream side which leads to development of non-linear weirs e.g., Labyrinth (LW) and Piano Key Weirs (PKW) to increase weir length and discharge capacity within a fixed overflow width. The labyrinth weir and the PKW have an increased weir length through the use of a polygonal weir plan. A labyrinth weir is a linear weir that is “folded” in plan-view to increase the crest length for a given channel or spillway width which offer several advantages when compared to linear weirs. Labyrinth weirs provide an increase in crest length for a given channel width, thereby increasing flow capacity for a given upstream head. As a result of the increased flow capacity, these weirs require less free board in the upstream reservoir than linear weirs, which facilitates flood routing and increases reservoir storage capacity under base flow conditions. The objective of this experimental study is hydraulic comparison of different labyrinth weir by compiling published design methodologies and weir information.

Labyrinth weirs provide an effective means to increase the spillway discharge capacity of dams and often considered for renovation projects required due to increase in expected flood inflow to the reservoir of an existing dam. The geometry of a labyrinth weir causes complex three dimensional flow patterns and flow rate passing over the labyrinth is dependent on the crest length which can be controlled by modifying the number of folds. The labyrinth weir is suitable for situations where the structure length has to be limited and for improvement in performance of existing spillways. This type of weir is characterized by a broken-axis weir in plan, generally with the same polygonal pattern repeated periodically. Hence, for the same total width, the labyrinth weir will present larger crest lengths than the same total width. A labyrinth weir is capable to pass larger flow than a normal weir with same head over the crest and comparatively less construction and preservation costs. It has more consistent operation compared with gated spillways and hence a labyrinth weir is preferred over other overflow structures. It is also be a cost-effective choice in terms of elevation of crest of the dam and reservoir capacity for specified maximum head over the crest. Although it has a broad range of applications, its complex flow conditions and design is considered as drawback by designers.

2. Literature Review

Houstons (1983): It shows that a weir projecting into a reservoir has approximately 20% larger discharge than a similar in-channel labyrinth weir at comparable heads.

Cassidy et al. (1985): Describe a spillway providing protection against the possible maximum flood of an earth dam and reservoir in north central Oregon. The zoned-filled earth dam is 31 m high, across Six Mile Canyon. To counter a dam failure under maximum flood conditions, a labyrinth type spillway was integrated into the dam crest. After a description of the spillway requirements for two stages of reservoir development, various spillway types are discussed. Among the straight crest, the controlled crest, and the labyrinth crest types, the latter was selected for the final design for reasons stated previously. The straight crest length was 110 m so that two symmetrical triangular plan-shape labyrinth portions of 39° intended angle were selected along the 36.60 m wide over flow section, crest shape of semi-circular of diameter 0.46 m to increase the discharge.

Yildiz and Uzecek (1996): Determined that arced labyrinth discharge could be as much as twice that of a classical labyrinth spillway due to better flow accommodation. Non-channelized approach flow conditions have led to increased discharge capacity.

Copeland and Fletcher (2000): Have stated that the spillway capacity of labyrinth weir is sensitive to both the magnitude and direction of approach flows.

Falvey (2003): He explains that if the cycle alignment had been curved, the discharge coefficient would have been higher and he identified three additional model studies (Kizilcapinar, Sarioglan and Avon spillways) that were impacted by non-ideal approach flow conditions. These problems included: lower discharge capacity, turbulent flow over the crest, and uneven nappy aeration.

Kizilcapinar and Avon (2007): Labyrinth weir designs were eventually arced in an effort to improve discharge efficiency for Maria Cristina Dam (Spain) the approach flow conditions and discharge capacity could be improved with arching the labyrinth weir within the limited footprint area of the spillway. Seven-cycle labyrinth weir with six cycles arced was selected as the optimal design. These arced labyrinth weir studied demonstrate the usefulness of these types of labyrinth weirs and the merit of additional hydraulic research.

Crookston (2010): Concluded that the arced configurations were found to be the most efficient labyrinth weirs tested and can increase discharge efficiency as it improves the orientation of the cycle to the approaching flow (~90° to the weir center line).

Crookston and Tullis (2012): Introduced geometric parameter nomenclature specific to arced labyrinth weirs that nomenclature was adopted for his study. His research topics included free and submerged weir flows, uniform channel flow scour at check dams.

3. Methodology

The capacity of the labyrinth weir is a function of total head, 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. 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. To simplify the analysis, the effect of viscosity and surface tension could be neglected by selecting model and velocity of sufficient magnitude.

Definite guidelines and theoretical procedures pertaining to hydraulic design of this type of weir are not completely established. There are many factors such as head to crest height ratio, vertical aspect ratio, side wall angle, apex width, approach flow conditions and conveyance channel conditions that influence the capacity of weir and hydraulic design of labyrinth weir. This experimental study on the labyrinth weir has been performed to compare the hydraulic behavior of the different types of labyrinth weirs.

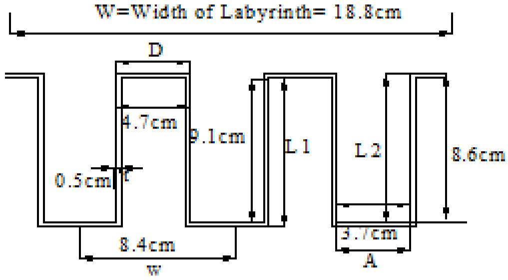

Figure 1: Schematic Diagram of the Rectangular Labyrinth Weir

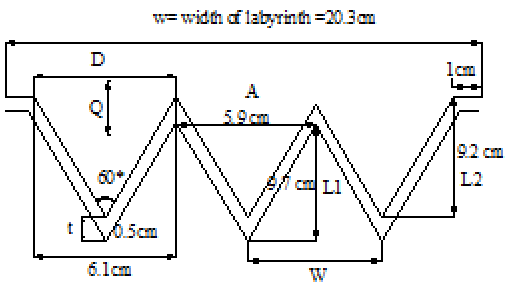

Figure 2: Schematic Diagram of the Triangular Labyrinth Weir

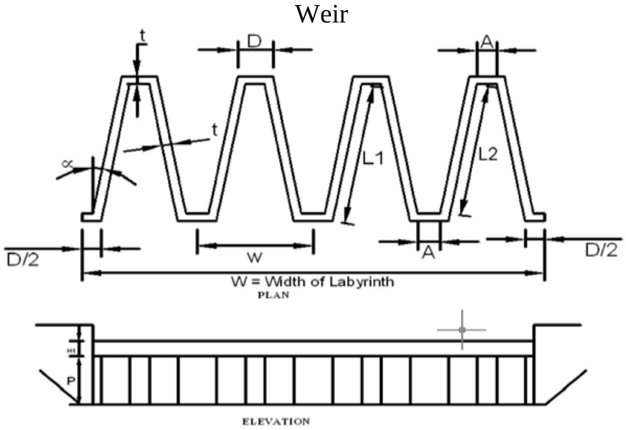

Figure 3: Schematic Diagram of the Trapezoidal Labyrinth weir

The discharge over labyrinth weir can be expressed as:

$$Q = CL\frac{2}{3} \times \sqrt{2g} \times L * Ht^{3/2}$$

Where,
Q = Discharge over a labyrinth weir
C_L= Discharge coefficient of the labyrinth weir
L= Effective length of labyrinth weir
H_t = Total head (Vo2/ 2g + h)
h = Piezometric head
g = Acceleration due to gravity

Figure 4: Experimental Setup

Figure 5: Rectangular Labyrinth Weir

Figure 6: Triangular Labyrinth Weir

Figure 7: Trapezoidal Labyrinth Weir

Table 1: Experimental Observations

S. No.	Rectangular Normal weir		Rectangular Labyrinth weir		Triangular Labyrinth weir		Trapezoidal Labyrinth weir	
	H (cm)	Q act. (cm³/s)	H (cm)	Q act. (cm³/s)	H (cm)	Q act. (cm³/s)	H (cm)	Q act. (cm³/s)
1	2.3	627.75	0.85	548.55	0.6	436.11	0.3	327.01
2	2.8	657.46	1	838.22	0.7	555.56	0.5	407.5
3	3.75	1095.29	1.1	831.26	0.9	846.02	0.6	783.7
4	4	1203.37	1.3	1075.27	1	971.82	0.7	785.55
5	4.3	1253.13	1.4	1251.56	1.2	1305.48	0.8	850.34
6	4.5	1438.85	1.55	1347.71	1.4	1494.77	1	1200.48
7	4.7	1379.31	1.7	1408.45	1.45	1610.31	1.1	1233.05
8	4.9	1538.46	1.8	1492.54	1.5	1666.67	1.15	1310.62

Table 2: Comparison of Coefficient of Discharge

S. No.	Rectangular Normal weir	Rectangular Labyrinth Weir	Triangular Labyrinth Weir	Trapezoidal Labyrinth Weir
1	0.38	0.34	0.56	0.7
2	0.3	0.4	0.56	0.59
3	0.32	0.37	0.59	0.69
4	0.32	0.35	0.58	0.69
5	0.3	0.36	0.59	0.61
6	0.32	0.34	0.54	0.62
7	0.31	0.31	0.55	0.55
8	0.3	0.3	0.54	0.55

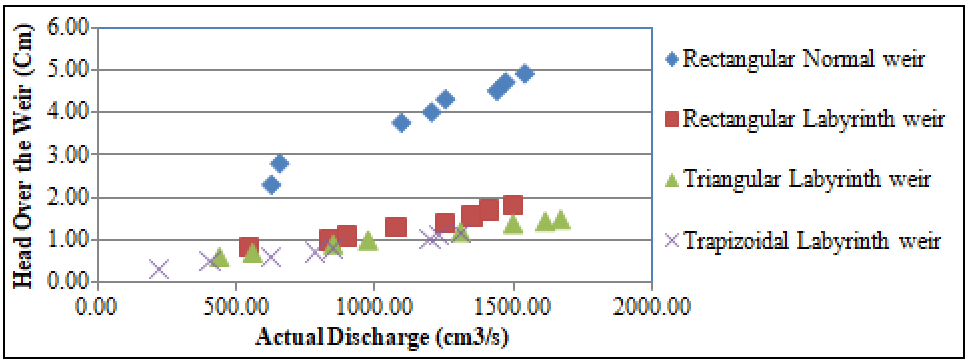

Figure 8: Comparison of Head over the weir with Actual Discharge

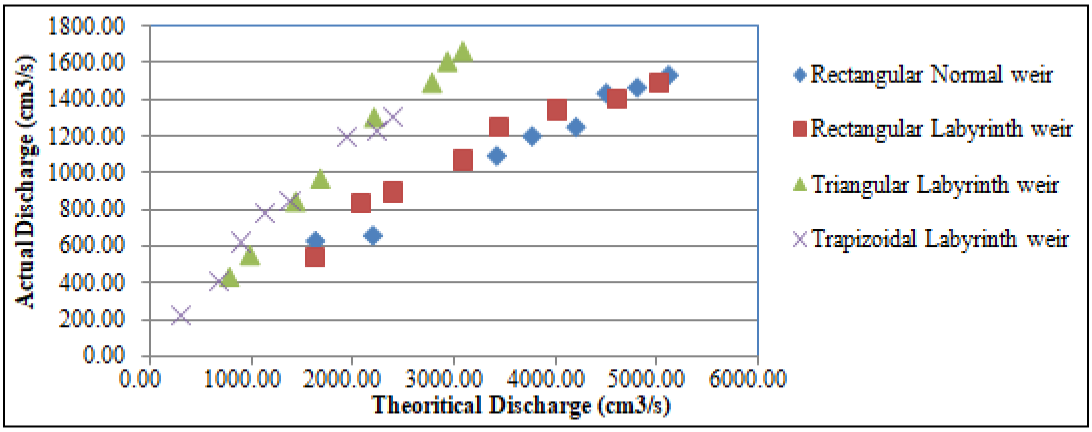

Figure 9: Comparison of Actual Discharge with theoretical Discharge

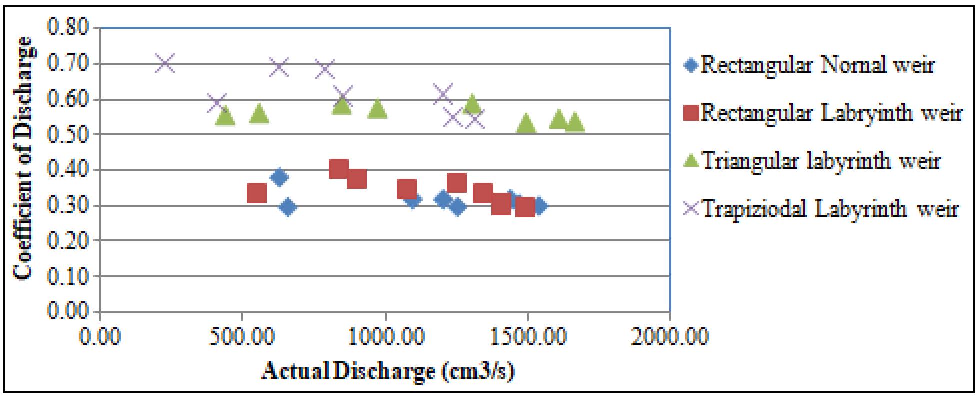

Figure 10: Comparison of Coefficient of Discharge with Actual Discharge

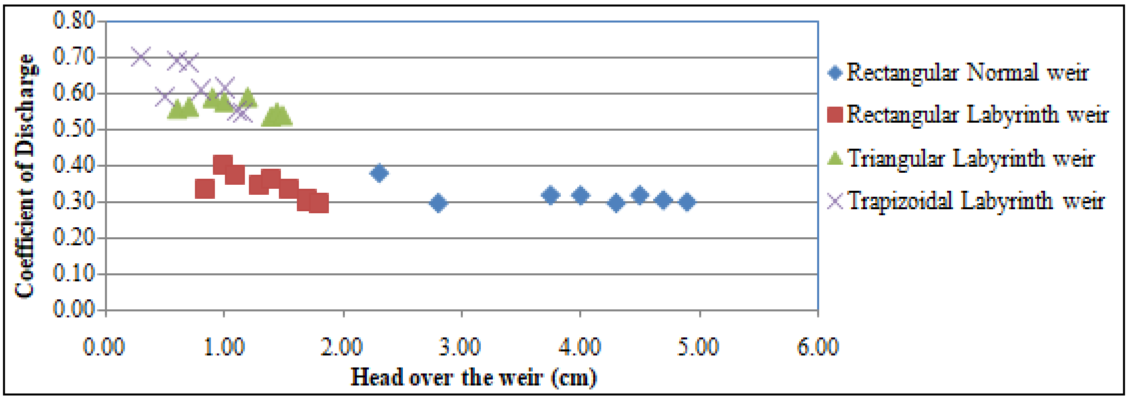

Figure 11: Comparison of Coefficient of Discharge with Head over the weir

4. Conclusions

1) Labyrinth weirs can pass large flows at comparatively low heads. The crest shape is one of the most important factors which affect the discharge capacity for labyrinth weirs.
2) It has found that the labyrinth weirs are hydraulically more efficient than other normal weir.
3) The discharge over the labyrinth weir is same as an equivalent of length straight weir for low head, with increase in head over the weir, the coefficient of discharge continues to decrease due to interference of jet and the weir capacity ultimately equal to that of the linear weir having crest length equal to the channel width. As the head increases the labyrinth weir becomes less efficient and hence the coefficient of discharge decreases.
4) Triangular and trapezoidal shaped labyrinth cycles are more efficient than rectangular labyrinth weir cycles based on a discharge per unit length.

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