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PERFORMANCE EVALUATION OF FLOW THROUGH TRIANGULAR WEIRS WITH BOTTOM ORIFICES

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ABSTRACT

This study attempted to evaluate the performance capacity of Triangular weirs with bottom orifices by varying the crest angles, diameters and number of orifices. Forty- Eight (48) triangular weirs with bottom orifices with crest angles of degrees 45^0, 60^0, and 90^0 with varying orifice sizes of diameters 6.5 mm, 7.5 mm and 8.5 mm and the number of orifices ranging from one to five. The analysis of the results indicates that, the discharge (Q) increases with an increase in effective head above crest (Ha) while the discharge coefficients (C_d) are found increasing steadily as the number of orifices and diameter increases with a minimum and maximum C_d of 0.3128 and 1.7986 respectively while the hydraulic performance of the models increasing as the number of orifices increases with the best hydraulic performance of the weirs determined to be 1.7630 at the model of angle 90^0 with five orifices of diameter 8.5 mm.

Keywords: Hydraulic performance, bottom orifices, discharge coefficient.

INTRODUCTION

A weir is an engineered structure used to measure free surface flows. In streams, canals, and rivers weirs are most often constructed mid-channel and oriented perpendicular to the flow. All weirs create backwater that causes a decrease in flow velocity upstream from the weir. If the flow carries sediment, this velocity reduction results in sedimentation in the channel upstream from the weir. Sedimentation alters approach flow conditions and leads to flow measurement errors, as most weir stage-discharge relations are derived without consideration of sedimentation.

Alhamid *et al.* (1999), proposed a combination device from the V-notch weir and rectangular sluice gate to reduce the sediment problem upstream the weir and to increase its capacity. Different geometric combination models were tested experimentally. Results indicated that the flow through the device is affected by the flow parameters and device geometry. Further, a semi-empirical discharge equation was developed with an absolute error of 4 %.

Abozeid *et al.* (2010) investigated the characteristics of clear overfill weirs provided with bottom openings. They designed nine weir models in a horizontal laboratory flume and used a range of weir heights, opening diameters, downstream water depths, and discharges to cover three weir flow cases, i.e., free pipe- free weir, submerged pipe - free weir, and submerged pipe- submerged weir. Besides, multiple regression equations were developed based on dimensional analysis to compute discharge for the combined device and all conditions of flow. Their findings were however, limited to a single orifice.

Hayawi *et al.* (2009), investigated experimentally the free flow through a combined rectangular weir with three different widths over a semi-circular gate of a constant diameter. Also, the distance below the weir edge and the semi-circular gate were changed three times. It was found that the values of C_d ranged from around 0.522 to 0.853 with an average of 0.695. Besides, a multi-regression model was developed to estimate C_d for the combined device with a percentage of error ±10 %. In this study, the orifice diameter was not varied.

Amery *et al.* (2015), experimentally tested the discharge coefficient of a compound sharp-crested side weir consisting of triangular-rectangular sections with various crest heights and apex angles. They concluded that the discharge coefficient of a triangular-rectangular composite weir depends on the Froude number, weir crest height to the upstream water depth ratio, and the weir length to the upstream depth ratio. Besides, two equations were developed based on experimental data and regression analysis to estimate the discharge coefficient for this compound weir.

Many researchers have studied the head–discharge relations for flows over rectangular sharp-crested and broad-crested weirs with a simple cross-section shape, such as rectangular, triangular, trapezoidal, truncated triangular, and others (French 1987; Ranga Raju 1993; Boiten and Pitlo 1982; Khalifa *et al.*, 2021; Umar *et al.*, 2018). This current work therefore is focused on the investigation of the performance capacity of Triangular weirs with bottom orifices by varying the crest angles, diameters and number of orifices, since there is a lacuna in considering the performance of the composite structure in these researches reviewed in the literatures.

Theoretical background:

The flow formula of triangular weirs and Circular Orifices was examined as follows;

$$Q_{theo.W} = \frac{8}{15}\sqrt{2g}\,Tan\frac{\theta}{2}H^{\frac{5}{2}} \quad (1)$$

$$Q_{theo.O} = A\sqrt{2gh} \quad (2)$$

Where $Q_{theo.W}$ is theoretical discharge passing over a triangular crest weir, g is the gravitational acceleration, θ is the angle between the sides of the notch, H is upstream head over the bottom edge of triangular weir, $Q_{theo.O}$ is theoretical discharge through the orifice, h is head of orifice, A is area of the orifice, expressed as $\frac{\pi}{4}D^2$ where D is orifice diameter, and h is the head above the orifice Centre to the water surface level.

The true discharge from weir and orifice are always less than the theoretical discharge because of the effects of friction, viscosity and the contraction of the area as flow passes through them. The coefficient of discharge; C_d is the product of C_v coefficient of velocity, and C_c, coefficient of contraction. Thus; equations (1) and (2) becomes,

$$Q_{act.W} = Cd_w \frac{8}{15}\sqrt{2g}\,Tan\frac{\theta}{2}H^{\frac{5}{2}} \quad (3)$$

$$Q_{act.O} = Cd_o \frac{\pi}{4}D^2\sqrt{2gh} \quad (4)$$

where $Q_{theo.W}$ is actual discharge passing over a triangular weir, $Q_{theo.O}$ is actual discharge passing through the orifice, while Cd_w and Cd_o are weir discharge coefficient and orifice discharge coefficient respectively.

To Compute the discharge via the suggested composite weir, the equations of discharge over the rectangular weir and through the orifice will be summed together. The actual discharge passing through the composite device becomes;

$$Q_{act.C} = Cd_w \frac{8}{15}\sqrt{2g}\,Tan\frac{\theta}{2}H^{\frac{5}{2}} + Cd_o \frac{\pi}{4}D^2\sqrt{2gh} \quad (5)$$

where $Q_{act.C}$ is the actual discharge for the composite device

Also, equation (5) can be written as thus;

$$Q_{act.C} = CdQ_{theo.C} \quad (6)$$

where Cd is the discharge coefficient of a combined weir, $Q_{theo.C}$ is the theoretical discharge of the combined weir: i.e.

$$Q_{theo.C} = Q_{theo.W} + Q_{theo.O} \quad (7)$$

MATERIALS AND METHODS

Materials

The experiment was conducted in a tilting flume of 6.1 m length with 0.3 m wide and 0.3 m deep at the hydraulic laboratory of the department of Water Resources and Environmental Engineering, Ahmadu Bello University, Zaria. Forty- eight (48) weir models were classified into three groups based on the value of the crest angles. For each of the groups, the crest angle was kept constant while the orifice diameter was varied three times (6.5 mm, 7.5 mm and 8.5 mm) with the number of orifices varying from 1 to 5 for each of the diameters. Table 1 shown below gives the detail description of the experimental models used for the work.

Experimental Procedure

The experiments were carried out in a hydraulic bench channel of length 610 cm, width 30 cm and height 31.5 cm with the main tank under the bench flume as seen in figure 2 below. Water was delivered from the main tank to the upstream inlet tank by a centrifugal pump with a rated capacity.

The bench bed was maintained during all the tests at a horizontal slope. Forty-eight models of a combined composite device were made from 1 cm thick plywood sheets, with the first being a triangular crested weir without a bottom orifice and considered standard. Details of the said sample of the proposed combined device is shown in figure 1 and table 1;

For all models, the base of the triangular weir was 7.0 cm from the centre of the orifices. The experimental procedures used are summarized below.

The triangular crested weir was installed in the flume with the help of sealants to prevent leakage, which was levelled. Supplying the channel with a specific discharge of water by adjusting a control valve in the bench supply line. Forty-eight models were fabricated with varying diameters and numbers of orifices and the experiment ran for each model and various heads and their corresponding discharge times recorded

The flow rate was increased at constant interval. The pump was activated and the discharge adjusted using a control valve and the reading of the point gauge recorded to give head above rectangular crested weir required for the calculation of the estimated discharge.

At the beginning of each run, the control valve was adjusted to alter the head. For each head recorded, the actual discharge was measured by direct method using the weighing arrangement provided at the tail end of the flume.

The previous steps were repeated for each of the six runs of experiment conducted for each model.

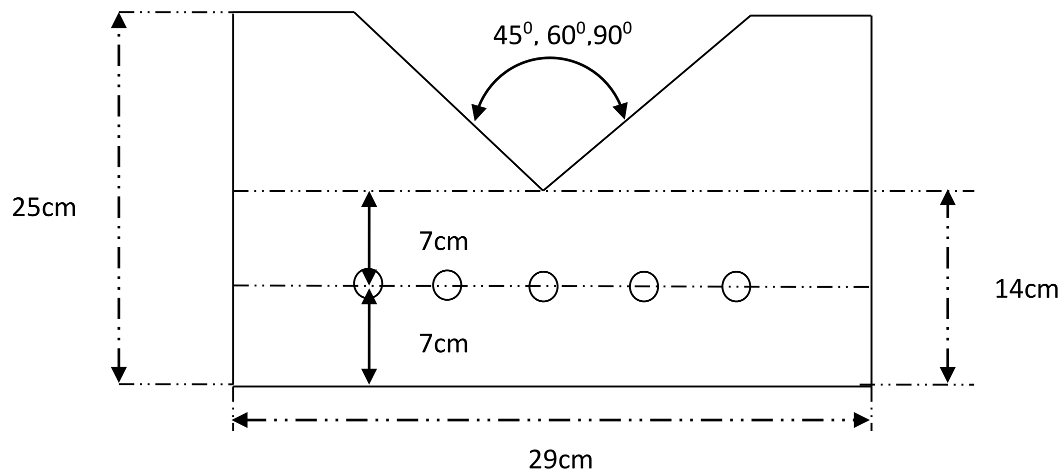

Figure 1: The sketch of the weir with bottom orifices

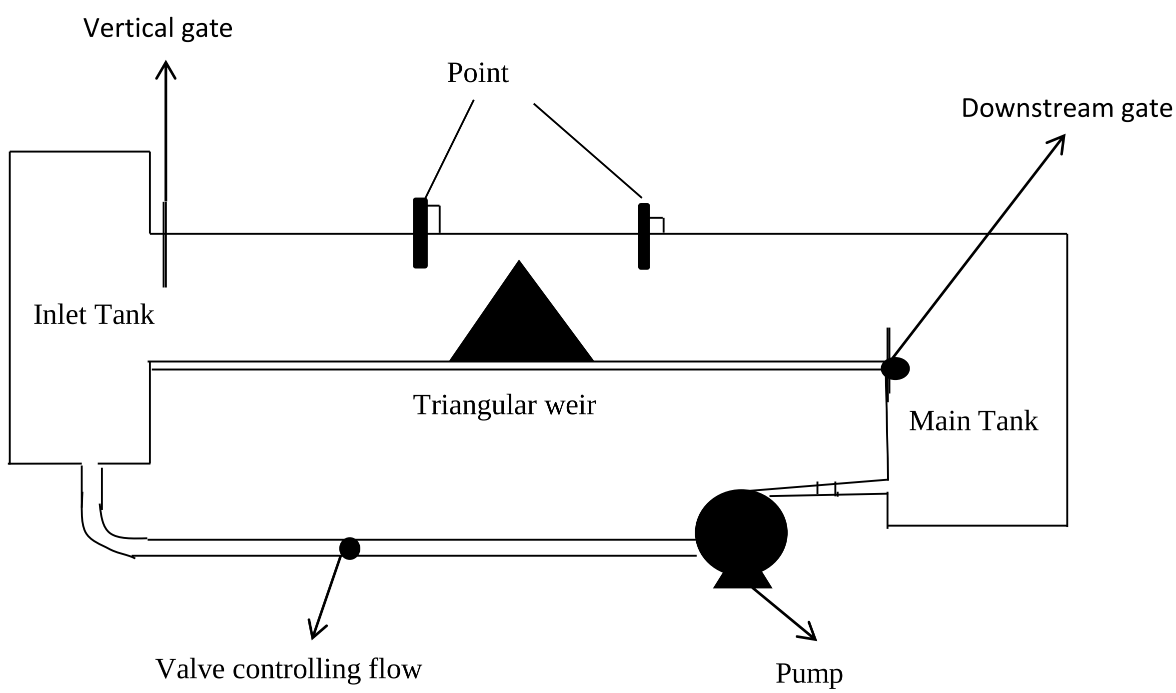

Figure 2: The experimental setup of the weir model

Hydraulic Performance

The best way to determine the performance of triangular weir with bottom orifices is to compare the discharge capacity of this type of weir with the discharge capacity of sharp crested normal weir having the same channel width and upstream effective head over the crest. The magnification factor of triangular weir with bottom orifices can be evaluated by estimating the ratio of discharge flowing over the triangular weir with bottom orifice (Q_{tw}) to the discharge flowing over sharp crested normal weir (Q_{nw}) having the same channel width and the same upstream effective head. (i.e., Q_{tw}/Q_{nw}). To estimate the discharge passing over sharp crested normal weir (Q_{nw} in m^3 /s), the well-known Rehbock equation seen in (eq. 8) below was used.

$$Q_{nw} = \frac{2}{3}\sqrt{2g}\left(0.611 + 0.8\frac{H_a}{P}\right).B.H_a{}^{1.5} \qquad (8)$$

Where B = channel width (crest length of sharp crested normal weir) in meters, g = acceleration due to gravity (m/s^2), P = height of the weir (m) and H_a = upstream effective head (total head) above crest in meters.

Table 1: The experimental weir models

Model No	Description	Angles (^{0})	Diameters (mm)
1	Standard weir	45, 60 & 90	No orifice
2	Standard weir with one orifice	45, 60 & 90	6.5
3	Standard weir with two orifices	45, 60 & 90	6.5
4	Standard weir with three orifices	45, 60 & 90	6.5
5	Standard weir with four orifices	45, 60 & 90	6.5
6	Standard weir with five orifices	45, 60 & 90	6.5
7	Standard weir with one orifice	45, 60 & 90	7.5
8	Standard weir with two orifices	45, 60 & 90	7.5
9	Standard weir with three orifices	45, 60 & 90	7.5
10	Standard weir with four orifices	45, 60 & 90	7.5
11	Standard weir with five orifices	45, 60 & 90	7.5
12	Standard weir with one orifice	45, 60 & 90	8.5
13	Standard weir with two orifices	45, 60 & 90	8.5
14	Standard weir with three orifices	45, 60 & 90	8.5
15	Standard weir with four orifices	45, 60 & 90	8.5
16	Standard weir with five orifices	45, 60 & 90	8.5

RESULTS AND DISCUSSION

Water Surface Profile

The graph in figure 4.1 show the water surface profile of the channel using the measured water depth in Appendix B1 for six various discharges. Thus, the point gauge was placed at 30 cm from the weir for accurate measurement of the discharge.

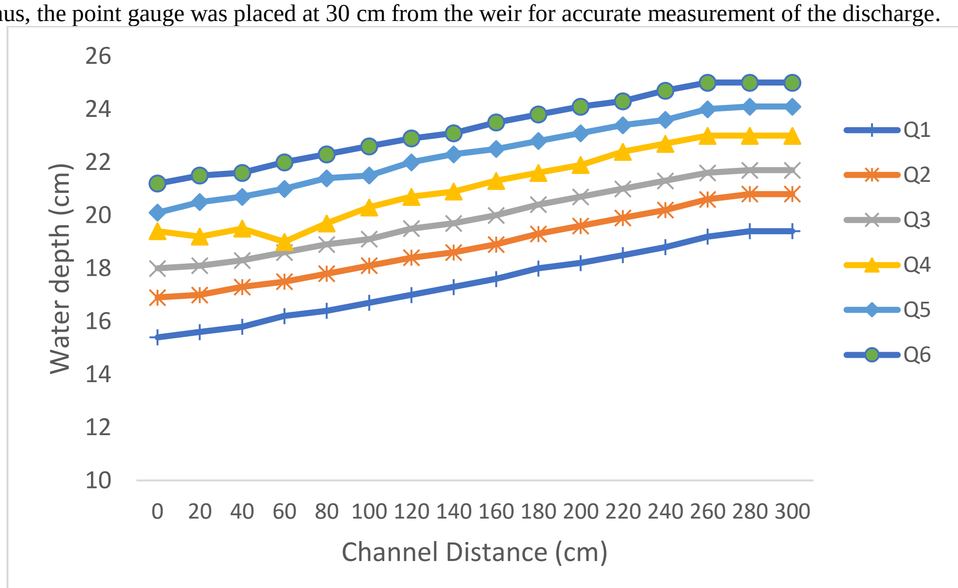

Figure 1: Graph showing Water Surface Profile

Variation of CD with Ha/P

The effects of CD with Ha/P for triangular weirs with bottom orifices of different crest angles (45^0, 60^0, 90^0), and varying orifice diameters of 6.5 mm, 7.5 mm and 8.5 mm with different number of orifices (1 to 5) are plotted in fig. 2-4.

As shown from the graphs, one may observe that the discharge coefficient (CD) increases with the increase of Ha/ P values for both values of crest angle, diameter and number of orifices of the weir model. This behavior may be attributed to the fact that the efficiency of the composite triangular weir model increases as the effective water discharge above the crest (Ha) increases, consequently, the value of discharge Coefficient (C_d) increases. This behavior holds true for all values of weir models with angles 45^0, 60^0, and 90^0 with constant orifice diameters of 6.5 mm, 7.5 mm and 8.5 mm with different number of orifices ranging from 1 to 5 considered for each of the crest angles.

Considering the impact of the crest angles on the coefficient of discharge (C_d), it's clear in figure 4 that weir models of crest angle 90^0 offer higher values of C_d than those of angles 45^0 and 60^0 as seen in figs. 2 and 3. This may be attributed to the fact that models of small crest angles (45^0 and 60^0) as experimented from this study may not have enough space for easy and free flow over the weir models. This is however, contrary to the findings of Bahzad, 2020 who experimented the hydraulic performance of circular crested oblique weirs.

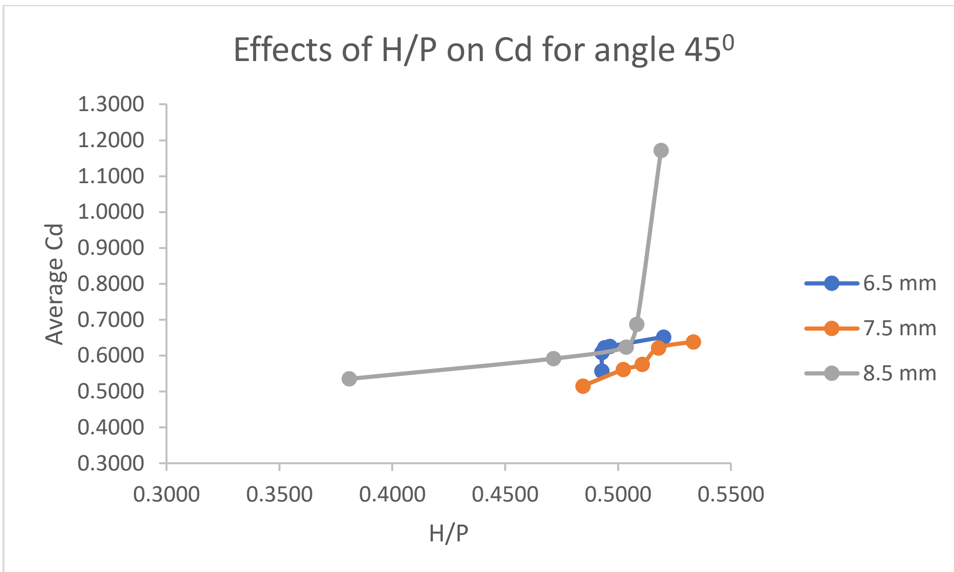

Figure 2: Effects of Cd on H/P for angle 45^0

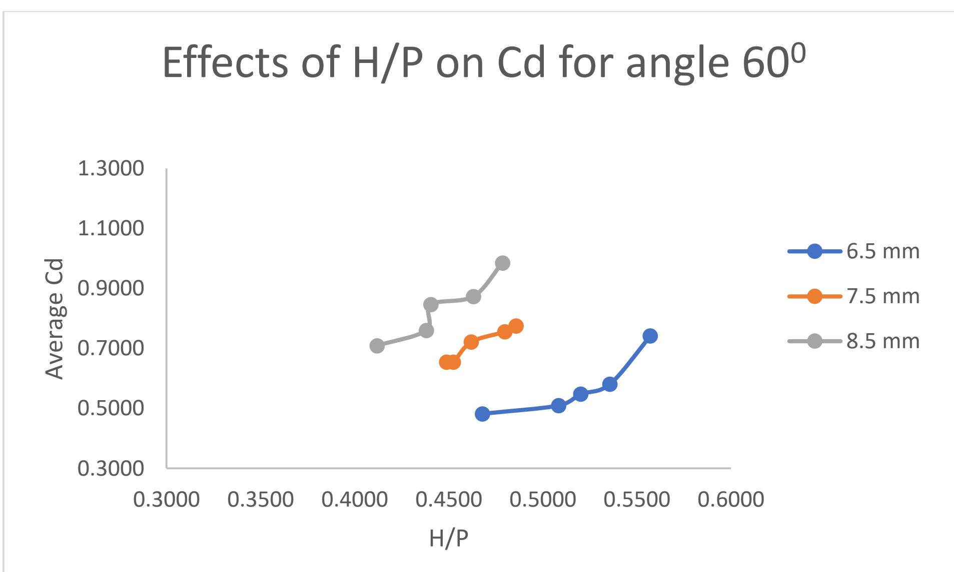

Figure 3: Effects of Cd on H/P for angle 60^0

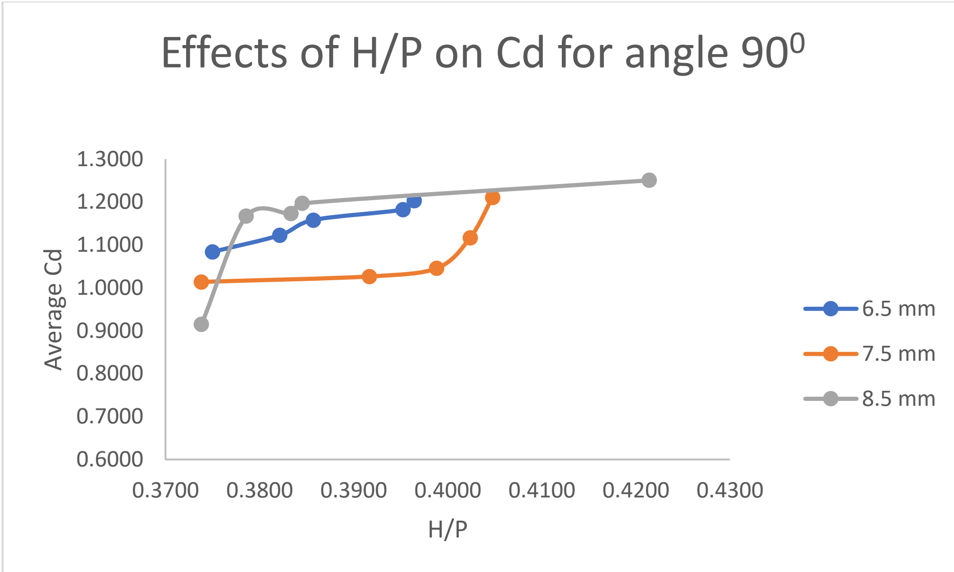

Figure 4: Effects of Cd on H/P for angle 90^0

Hydraulic Performance of the Triangular weir with bottom orifices

From the results, as seen in table 2 below, it was observed that the best hydraulic performance of the weirs was determined to be 1.7630 at the model of angle 90^0 with five orifices of diameter 8.5 mm.

Table 2 shows that triangular weir with bottom orifice of angle 90^0 having orifice diameter of 8.5 mm offers the highest values of percentage increase in discharges ranging between 155.65% and 176.30% giving this weir model the most favourable one among the other weir models considered.

Bahzad (2020) in his studies on the hydraulic performance of circular crested oblique weirs recorded the highest values of percentage increase in discharges ranging from 147.3% and 174.9% while Noori and Aaref, 2017, in their study on the hydraulic performance of triangular plan form weirs, recorded the highest values of percentage increase in discharges ranging between 123.7% and 137.9%. This demonstrates that circular crested oblique weirs give higher discharge magnification and better performance compared to circular crested triangular plan form weirs.

Table 2: Hydraulics Performance of the Triangular weir model with bottom orifices

Angle 45^0 with diameter 6.5 mm															
	Orifice 1			Orifice 2			Orifice 3			Orifice 4			Orifice 5		
S/N	Q_{tw}	Q_{nw}	Q_{tw}/Q_{nw}	Q_{tw}	Q_{nw}	Q_{tw}/Q_{nw}	Q_{tw}	Q_{nw}	Q_{tw}/Q_{nw}	Q_{tw}	Q_{nw}	Q_{tw}/Q_{nw}	Q_{tw}	Q_{nw}	Q_{tw}/Q_{nw}
1	0.0004	0.0010	0.3527	0.0004	0.0009	0.4158	0.0004	0.0012	0.3011	0.0004	0.0010	0.3637	0.0004	0.0011	0.3369
2	0.0007	0.0012	0.5436	0.0007	0.0011	0.6153	0.0007	0.0013	0.5094	0.0007	0.0014	0.4660	0.0006	0.0011	0.5715
3	0.0010	0.0016	0.6130	0.0010	0.0014	0.6908	0.0009	0.0016	0.5936	0.0009	0.0015	0.5971	0.0009	0.0012	0.7986
4	0.0011	0.0017	0.6401	0.0012	0.0016	0.7285	0.0011	0.0017	0.6433	0.0011	0.0018	0.6165	0.0011	0.0012	0.9563
5	0.0021	0.0028	0.7527	0.0020	0.0024	0.8400	0.0020	0.0020	0.9807	0.0020	0.0020	0.9810	0.0019	0.0013	1.4302
6	0.0022	0.0029	0.7778	0.0024	0.0028	0.8836	0.0022	0.0021	1.0527	0.0022	0.0021	1.0181	0.0023	0.0013	1.6932
Angle 45^0 with diameter 7.5 mm															
1	0.0004	0.0010	0.3624	0.0004	0.0010	0.3615	0.0004	0.0010	0.3714	0.0004	0.0011	0.3170	0.0004	0.0008	0.4772
2	0.0007	0.0013	0.4960	0.0007	0.0012	0.5537	0.0007	0.0011	0.5999	0.0007	0.0013	0.5028	0.0007	0.0012	0.5637
3	0.0009	0.0017	0.5517	0.0009	0.0015	0.6164	0.0009	0.0014	0.6559	0.0009	0.0016	0.5817	0.0009	0.0016	0.5915
4	0.0012	0.0020	0.5967	0.0012	0.0017	0.6739	0.0012	0.0017	0.7129	0.0012	0.0019	0.6099	0.0011	0.0018	0.6209
5	0.0019	0.0029	0.6636	0.0019	0.0025	0.7536	0.0020	0.0024	0.8150	0.0019	0.0022	0.8579	0.0019	0.0020	0.9395
6	0.0022	0.0028	0.7902	0.0022	0.0028	0.8073	0.0024	0.0028	0.8715	0.0024	0.0027	0.8746	0.0024	0.0024	1.0011
Angle 45^0 with diameter 8.5 mm															
1	0.0004	0.0034	0.1058	0.0004	0.0014	0.2650	0.0004	0.0012	0.2904	0.0004	0.0011	0.3311	0.0004	0.0008	0.4480
2	0.0007	0.0037	0.1799	0.0007	0.0015	0.4403	0.0007	0.0015	0.4423	0.0006	0.0012	0.5557	0.0007	0.0009	0.7643
3	0.0009	0.0044	0.2053	0.0009	0.0017	0.5186	0.0009	0.0016	0.5484	0.0009	0.0014	0.6311	0.0009	0.0009	0.9542
4	0.0011	0.0052	0.2171	0.0011	0.0019	0.5616	0.0011	0.0018	0.5870	0.0011	0.0016	0.6697	0.0011	0.0010	1.1264
5	0.0019	0.0053	0.3511	0.0017	0.0021	0.8244	0.0019	0.0019	0.9669	0.0018	0.0018	1.0020	0.0018	0.0012	1.5786
6	0.0023	0.0056	0.4069	0.0021	0.0022	0.9746	0.0022	0.0020	1.1009	0.0023	0.0019	1.1626	0.0022	0.0014	1.6068
Angle 60^0 with diameter 6.5 mm															
1	0.0004	0.0011	0.3268	0.0004	0.0010	0.3494	0.0004	0.0009	0.3839	0.0004	0.0009	0.3860	0.0004	0.0009	0.4136
2	0.0007	0.0013	0.5033	0.0007	0.0012	0.5675	0.0007	0.0011	0.6196	0.0007	0.0010	0.6474	0.0007	0.0010	0.6872
3	0.0009	0.0015	0.6385	0.0009	0.0014	0.6773	0.0009	0.0012	0.7546	0.0009	0.0013	0.7404	0.0009	0.0011	0.8502
4	0.0012	0.0017	0.7143	0.0012	0.0016	0.7272	0.0012	0.0014	0.8032	0.0012	0.0015	0.7939	0.0012	0.0012	0.9688
5	0.0020	0.0017	1.1151	0.0019	0.0017	1.1078	0.0018	0.0016	1.1766	0.0019	0.0015	1.2596	0.0018	0.0013	1.3960
6	0.0023	0.0019	1.2344	0.0024	0.0018	1.3381	0.0024	0.0017	1.4019	0.0024	0.0016	1.4641	0.0023	0.0016	1.4854
Angle 60^0 with diameter 7.5 mm															
1	0.0004	0.0014	0.2583	0.0004	0.0015	0.2311	0.0004	0.0013	0.2747	0.0004	0.0013	0.2756	0.0004	0.0011	0.3113
2	0.0007	0.0016	0.4184	0.0007	0.0017	0.3783	0.0007	0.0016	0.4090	0.0007	0.0014	0.4541	0.0007	0.0012	0.5346
3	0.0009	0.0016	0.5875	0.0010	0.0020	0.4787	0.0009	0.0019	0.5003	0.0009	0.0016	0.6017	0.0010	0.0014	0.6648
4	0.0011	0.0019	0.5643	0.0011	0.0022	0.5169	0.0011	0.0021	0.5109	0.0011	0.0018	0.6025	0.0011	0.0016	0.7016
5	0.0018	0.0021	0.8535	0.0018	0.0024	0.7647	0.0018	0.0022	0.8140	0.0018	0.0020	0.8984	0.0018	0.0017	1.1062
6	0.0022	0.0022	0.9720	0.0024	0.0025	0.9827	0.0022	0.0024	0.9505	0.0022	0.0022	1.0020	0.0024	0.0017	1.3486
Angle 60^0 with diameter 8.5 mm															
1	0.0003	0.0009	0.4084	0.0003	0.0009	0.3781	0.0004	0.0011	0.3115	0.0004	0.0011	0.3113	0.0004	0.0010	0.3685
2	0.0007	0.0011	0.5813	0.0007	0.0011	0.5988	0.0007	0.0013	0.4955	0.0007	0.0013	0.5091	0.0007	0.0011	0.5991
3	0.0009	0.0013	0.7372	0.0009	0.0012	0.7565	0.0010	0.0015	0.6251	0.0010	0.0015	0.6437	0.0010	0.0013	0.7223
4	0.0011	0.0016	0.7212	0.0011	0.0015	0.7648	0.0011	0.0017	0.6643	0.0011	0.0017	0.6580	0.0011	0.0016	0.7092
5	0.0019	0.0019	0.9807	0.0018	0.0017	1.0764	0.0018	0.0019	0.9437	0.0017	0.0018	0.9708	0.0018	0.0016	1.0984
6	0.0022	0.0020	1.0547	0.0021	0.0018	1.1629	0.0023	0.0019	1.1675	0.0022	0.0019	1.1791	0.0022	0.0018	1.2254
Angle 90^0 with diameter 6.5 mm															

1	0.0003	0.0008	0.4242	0.0003	0.0008	0.4396	0.0004	0.0007	0.5195	0.0004	0.0007	0.5206	0.0003	0.0006	0.5388
2	0.0006	0.0011	0.6131	0.0006	0.0009	0.7579	0.0007	0.0008	0.8587	0.0007	0.0008	0.7887	0.0006	0.0008	0.7875
3	0.0009	0.0012	0.7788	0.0009	0.0009	0.9843	0.0009	0.0009	1.0681	0.0009	0.0010	0.9499	0.0009	0.0010	0.9396
4	0.0011	0.0013	0.8549	0.0011	0.0010	1.1041	0.0011	0.0010	1.1229	0.0012	0.0011	1.0201	0.0011	0.0011	1.0170
5	0.0019	0.0014	1.3382	0.0019	0.0012	1.5966	0.0019	0.0012	1.5935	0.0020	0.0012	1.5936	0.0020	0.0012	1.6302
6	0.0021	0.0015	1.3824	0.0022	0.0014	1.5998	0.0022	0.0013	1.6791	0.0022	0.0013	1.6853	0.0022	0.0013	1.6962
Angle 90^0 with diameter 7.5 mm															
1	0.0003	0.0007	0.4756	0.0003	0.0006	0.5629	0.0003	0.0009	0.4079	0.0003	0.0008	0.4401	0.0003	0.0009	0.4087
2	0.0006	0.0008	0.7849	0.0006	0.0007	0.8832	0.0006	0.0010	0.6813	0.0007	0.0009	0.7605	0.0006	0.0009	0.7050
3	0.0009	0.0010	0.8640	0.0009	0.0009	1.0165	0.0009	0.0011	0.8481	0.0009	0.0010	0.9047	0.0009	0.0010	0.9471
4	0.0011	0.0012	0.9305	0.0011	0.0009	1.1928	0.0011	0.0011	1.0330	0.0011	0.0012	0.9652	0.0011	0.0010	1.1187
5	0.0020	0.0014	1.3561	0.0020	0.0014	1.4366	0.0020	0.0014	1.4394	0.0019	0.0014	1.3643	0.0020	0.0013	1.5362
6	0.0022	0.0015	1.4149	0.0022	0.0014	1.5395	0.0022	0.0014	1.5227	0.0022	0.0014	1.5390	0.0022	0.0014	1.6003
Angle 90^0 with diameter 8.5 mm															
1	0.0003	0.0009	0.4077	0.0004	0.0007	0.4965	0.0004	0.0006	0.5410	0.0003	0.0009	0.3796	0.0004	0.0007	0.4968
2	0.0006	0.0009	0.6996	0.0006	0.0009	0.7570	0.0006	0.0008	0.8152	0.0006	0.0010	0.6734	0.0006	0.0008	0.7746
3	0.0009	0.0010	0.9053	0.0009	0.0010	0.8862	0.0009	0.0010	0.9470	0.0009	0.0010	0.8764	0.0010	0.0011	0.9777
4	0.0011	0.0010	1.1246	0.0011	0.0011	0.9722	0.0011	0.0011	1.0007	0.0011	0.0011	1.0114	0.0011	0.0011	1.0141
5	0.0020	0.0014	1.4858	0.0020	0.0012	1.6332	0.0019	0.0012	1.6552	0.0020	0.0012	1.6789	0.0020	0.0012	1.6886
6	0.0022	0.0014	1.5565	0.0022	0.0013	1.7403	0.0022	0.0012	1.7404	0.0022	0.0012	1.7507	0.0022	0.0012	1.7630

CONCLUSION

In this experiment, the discharge coefficient and hydraulic performance of Triangular weirs with bottom orifices were examined by varying the number of crest angles, diameter of orifices and the orifice number. During the experiment, forty-eight weir models were tested in which their properties were varied.

The analysis of the results indicates that, the discharge (Q) increases with an increase in effective head above crest (Ha) while the discharge coefficients (C_d) are found increasing steadily as the number of orifices and diameter increases with a minimum and maximum C_d of 0.3128 and 1.7986 respectively. The hydraulic performance of the models also increases as the number of orifices increases with the best hydraulic performance of the weirs found between the range of 155.65% and 176.30% at the model of angle 90^0 with five orifices of diameter 8.5 mm.

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