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Hydraulic Performance of Flow over Normal and Inclined Compound Crested Weir Models

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Abstract

The overflow characteristics of Compound crested weir models were investigated experimentally using a laboratory flume. The crests of these weir models consist of two parts; the upstream part has a quarter round shape while the downstream part has standard sharp crested weir shape. Series of experiments were conducted by measuring discharges and water heads over the weir models for different weir crest radii of R = 2.5 cm, 3.5 cm, 4.5 cm and angles of weir inclination α = 300, 45°, 60^0 and 90° respectively to the direction of flow with a constant weir height P = 15 cm. It was observed that increase in the ratio of water head over the crest (h) to weir height (P) resulted in the corresponding increase in the discharge coefficient for all the weir models. The hydraulic performance for each of the weirs was determined in terms of the flow magnification factor. Hence, the model with R = 2.5 cm and α = 30^0 was selected as the best model because it had the highest discharge coefficient and flow magnification factor of 1.326 and 1.555 respectively.

Key words: Laboratory flume, Compound crested weir, Angle of weir inclination, Hydraulic Performance, Flow Magnification Factor.

Introduction

Weirs may be defined as overflow structures built across channels or rivers to divert or spill water. Designing spillway weirs of high head in a dam with shorter length of overflow section may cause the height of non-overflow section of the dam to be increased. The maximum water levels in the reservoir, is in-turn, increased leading to a greater area of submergence, which may not be permissible in an area where the cost of land is high (Ibrahim *et al*, 1988). In many situations where the topography of the site may have restrictions on the length of spillway weir that may be adopted- aligning the weir is included in plan so as to compress the length of crest within the limited lateral space available which in-turn lead to reduction in the water head over the weir (Thair and Tahssen, 2006).

Thair and Tahssen (2006) experimented on inclined compound crested weirs. At the end of their experimental work, they concluded with a discharge coefficient (C_d) equation which depends on water head on the weir (*h*), weir height (*P*) and crest radius (R). Also, they observed that; the C_d value increases as the ratio h/P increases for all the tested angles of compound weir inclination.

In addition, for certain value of the ratio h/P, the C_d value increases with the decreasing of the angle of weir inclination. The model with the smallest angle of weir inclination with the center line of the channel had a better performance than other models. The same was observed when Bhzad and Tahssen (2005) and Baghei *et al.* (2003) carried out an extensive study on inclined semi-circular and rectangular sharp-crested weirs respectively.

Furthermore, a comprehensive set of experiments was performed by (Kabiri-Samani *et al,* 2010), on weirs placed obliquely in a rectangular open channel. The main objectives were to investigate the effect of the weir angle relative to the approach flow direction on the behaviour and the hydraulic flow characteristics and to examine methods, such as using upstream guide vanes and inclined aprons, to increase the effective oblique weir length. Results indicate that by increasing the oblique angle, the effective length of the oblique weir increases significantly with subsequent increase in the weir performance.

The present study deals with flow over normal and inclined compound crested weir models which combine two faces; the upstream face is quarter round shape while the downstream face has standard sharp crested weir shape. They were fabricated and tested to compute the discharge coefficients and the hydraulic weir performances. The effect of weir inclination with the direction of flow on the weir performance was also investigated.

Materials and Methods

Experimental Method

The compound crested weir models constructed have a configuration of quarter round shape at the upstream and sharp shape at the downstream, as shown in Figure 1. The quarter round part is a quarter circle with a radius of R. This radius was depended according to the design criteria suggested by Abid-Ali (1986), in which the radius of the weir (R) should at-least equal to the height of the weir (P) divided by 12 i.e. $R=P/12$.

The experiment was conducted using the rectangular laboratory flume of the Hydraulics Laboratory of Water Resources and Environmental Engineering Department, Ahmadu Bello University, Zaria. Twelve models were fabricated and tested in which the crest radius (R), and inclined angles (α) were varied. The models were classified into four groups based on the value of the inclined angle (α = 90^0, 60^0, 45^0, 30^0). Each group was tested for three values of crest radius (R = 2.5cm, 3.5cm, 4.5cm) with the same weir height of P = 15 cm. All models were produced from wood and well varnished to give smooth surfaces. Every model was placed in the flume at a distance 4.0m downstream from the flume inlet and the desired inclined angle (α). Then the model was glued to the sides and bed of the flume. Afterwards, the testing programme was started by allowing different discharges to overtop the weir model. These discharges were kept constant throughout the experiment. For each discharge, upstream water surface profiles were found by measuring the heads over a number of grid points covering the region. Discharges that passed over the weirs were measured with the aid of a weighing machine and a stopwatch. Point gauges with vernier scales reading to 0.1 mm were used for the measurements of water heads. Figure 1 shows the plan views of both normal and inclined weirs with their cross section.

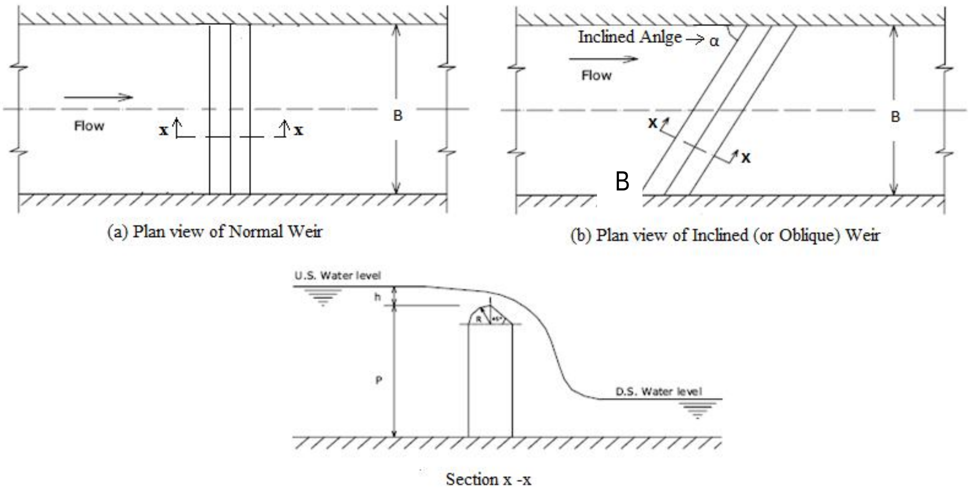

Figure 1: Schematic diagram of the compound crested weirs.

Water Surface Profile

In order to decide the point gauge location and to get rid of drawdown effects, a water surface profile study was carried out for different discharge values. In literature, the effective measurement point is considered as 3- 4*h* away from the weir location (Subramanya, 1986; Franzini and Finnemore, 1997).

Discharge Equation

The proposed equation for designing the compound crested weirs was the basic equation developed for linear weirs according to Chow (1959), expressed as Equation (1).

$$Q = \frac{2}{3} C_d L \sqrt{2g} h^{1.5} \qquad (1)$$

where
C_d = a dimensionless coefficient of discharge,
g = acceleration of gravity (m/s^2),
L = effective length of the weir (m), and
H = total head on the crest (m).

Therefore, the discharge coefficient C_d was taken as the ratio of actual discharge Q_{act} to the theoretical discharge Q_{theo}, given by:

$$C_d = \frac{Q_{act}}{Q_{theo}} \qquad (2)$$

where
C_d = discharge coefficient,
Q_{act} = actual discharge m^3/sec.
Q_{theo} = theoretical discharge m^3/sec.

The actual discharge (Q_{act}) was measured by using gravimetric method which was then converted to m^3/s using Equation (3), while the theoretical discharge was evaluated by using Equation (4).

$$Q_{act} = \frac{M}{t_{avg.}\rho} \quad (3)$$

where
M = mass of water (measured using a weighing machine, kg);
t_{avg} = average time (in seconds);
ρ = density of water = 1000kg/m^3

$$Q_{theo} = \frac{2}{3} L\sqrt{2g}h^{1.5} \quad (4)$$

where

$$L = \frac{B}{\sin\alpha} \quad (5)$$

where B being the width of the Channel

Hydraulic Performance of the Compound Weirs

For normal weirs, the hydraulic performance may be best represented by the magnification factor defined as the ratio of discharge passing over normal weir of compound crest (Q_{NC}) to the discharge passing over an imaginary normal sharp-crested weir of the same height (Q_{NS}). Values of Q_{NS} were obtained from the relevant Equation (6) recommended by British Standard Institute (1965).

$$Q_{NS} = \frac{2}{3}\sqrt{2g}\left(0.602 + 0.083\frac{h}{P}\right).L.(h + 0.0012)^{3/2} \quad (6)$$

For inclined weirs, the magnification factor is defined as the ratio of discharge passing over the inclined weir with compound crest (Q_{In}) to the discharge of normal weir with compound crest (Q_{NC}).

Results and Discussion

Water Surface Profile

The graph in Figure 2 illustrates the water surface profile in the channel using the measured water depths and distances from the weir under different flow rats. The x-axis of the graph represents the distance from the weir and y-axis represents the water height from the bottom of the channel. As can be seen, water surface is almost stationary after 0.70 m from the weir. As stated earlier, to be on the safe side, the point gauge is located 0.80 m upstream of the weir.

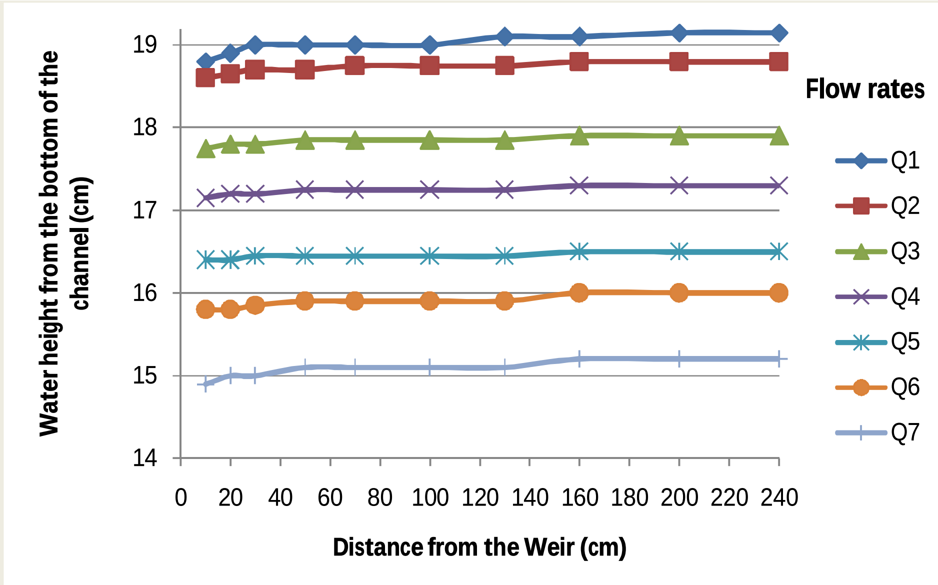

Figure 2: Water Surface Profile for Different Discharges

Discharge Coefficient

Figures 4, 5 and 6 show the variation of C_d with h/P for crest radii R=2.5cm, 3.5cm, 4.5cm with normal and inclined angles $\alpha=90^o$, 60^o, 45^o and 30^o, respectively. From these figures, the following points are noted: Firstly, the discharge coefficient (C_d) decreases with the increase of h/P values and for small values of h/P, the weir behaves almost ideally, giving high values of C_d. This behavior is because for small values of h/P, the discharge is small and the velocity head of flow is negligible. Secondly, weirs of inclined angle $\alpha = 30^0$ give higher values of C_d than those of 90^o, 60^o and 45^o because weirs of small inclined angles have longer lengths for the flow to pass over. Thirdly, weirs of crest radius R=2.5 cm give higher values of C_d than those of large crest radius.

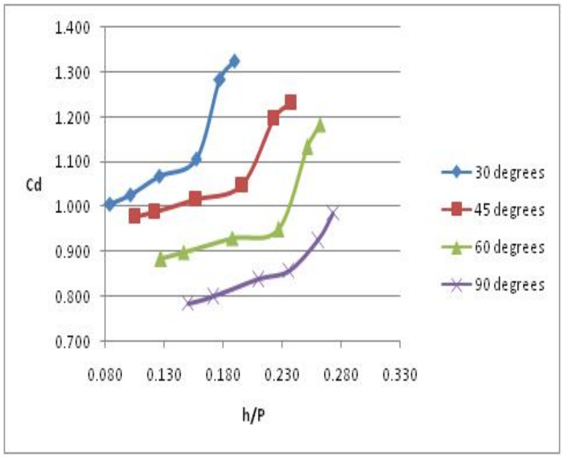

Figure 4: Variation of C_d with h/p for Normal and Normal and Inclined Weirs of Crest Radius R = 2.5cm

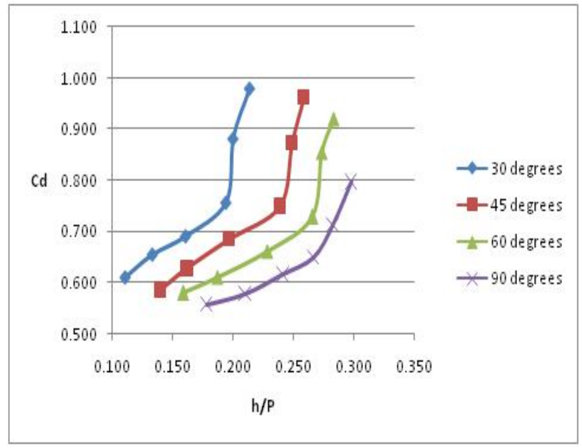

Figure 5: Variation of C_d with h/p for Inclined Weirs of Crest Radius R = 3.5cm

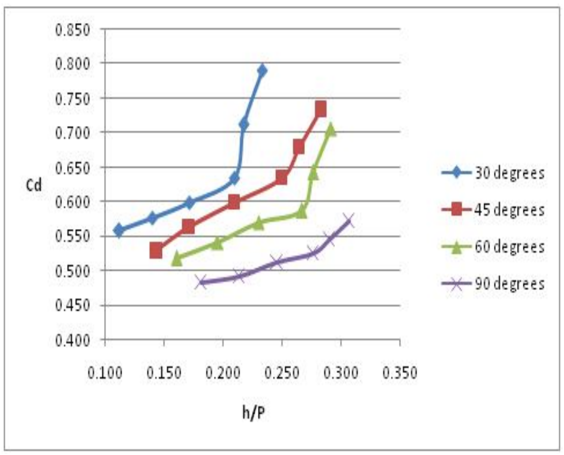

Figure 6: Variation of C_d with h/p for Normal and Inclined Weirs of Crest Radius R = 4.5cm

Hydraulic Performance of the Compound Weirs

The calculated actual discharges, Q_{act}, in Tables 1, 2 and 3 respectively were used to determine the weir performances in terms of the flow magnification factor. The flow magnification factors for the normal and inclined compound crested weir models are presented in Tables 4 and 5 for different values of crest radii R=2.5cm, 3.5cm and 4.5cm, respectively. From the flow magnification factors (Q_{NC}/Q_{NS}) for the normal in Table 4, one may observe that (Q_{NC}/Q_{NS}) increases with an increase in (h/P) value and values of magnification factor are always greater than unity, especially when R=2.5cm. This means that the normal weir of compound crest (R=2.5cm) performs better than those of sharp crest.

For inclined weirs, the magnification factor (Q_{In} /Q_{NC}) is shown in Table 5 for crest radius R=2.5cm, 3.5cm, 4.5cm and inclined angles $\alpha=60^0$, 45^0 and 30^0 respectively. From these results, the following can be deduced: Firstly, weirs of inclined angle $\alpha=30^0$ give greater values of magnification factor (better performance) than those of 60^0 and 45^0 because weirs of small inclined angle to the direction of flow have longer lengths for flow to pass over. Secondly, weirs of crest radius R=2.5cm give greater values of magnification factor (better performance) than those of larger crest radius. Thirdly, the magnification factor increases with the decrease of head to crest height ratio (h/P).

Table 1: Actual measured discharges over the weir model with R = 2.5cm

α = 90^0 Q_{act} (l/s)	**α = 60^0 Q_{act} (l/s)**	**α = 45^0 Q_{act} (l/s)**	**α = 30^0 Q_{act} (l/s)**
2.35	2.41	2.46	2.56
2.93	3.03	3.11	3.47
4.15	4.55	4.65	5.00
5.03	6.14	6.71	7.23
6.33	8.57	9.28	10.03
7.25	9.52	10.50	11.43

Table 2: Actual measured discharges over the weir model with R = 3.5cm

α = 90^0 Q_{act} (l/s)	**α = 60^0 Q_{act} (l/s)**	**α = 45^0 Q_{act} (l/s)**	**α = 30^0 Q_{act} (l/s)**
2.15	2.20	2.26	2.35
2.86	2.96	3.02	3.33
3.75	4.32	4.41	4.65
4.60	5.97	6.44	6.77
5.50	7.34	7.98	8.25
6.67	8.33	9.32	10.10

Table 3: Actual measured discharges over the weir model with R = 4.5cm

α = 90^0 Q_{act} (l/s)	**α = 60^0 Q_{act} (l/s)**	**α = 45^0 Q_{act} (l/s)**	**α = 30^0 Q_{act} (l/s)**
1.92	2.00	2.12	2.19
2.49	2.81	2.93	3.16
3.21	3.77	4.23	4.44
3.92	4.85	5.86	6.36
4.38	5.59	6.83	7.55
5.00	6.67	8.16	9.32

Table 4: Flow magnification factor for the Normal compound crested weir models

Magnification Factor (Q_{NC}/Q_{NS}), α = 90^0		
R = 2.5cm	**R = 3.5cm**	**R = 4.5cm**
1.181	0.845	0.732
1.212	0.881	0.750
1.279	0.941	0.785
1.310	0.994	0.806
1.416	1.091	0.836
1.510	1.221	0.877

Table 5: Flow magnification factor for the inclined compound crested weir models

Magnification Factor (Q_{In} /Q_{NC}), R=2.5cm			Magnification Factor (Q_{In} /Q_{NC}), R=3.5cm			Magnification Factor (Q_{In} /Q_{NC}), R=4.5cm		
$\alpha = 60^0$	$\alpha = 45^0$	$\alpha = 30^0$	$\alpha = 60^0$	$\alpha = 45^0$	$\alpha = 30^0$	$\alpha = 60^0$	$\alpha = 45^0$	$\alpha = 30^0$
1.025	1.049	1.091	1.018	1.046	1.089	0.943	0.998	1.032
1.034	1.061	1.184	1.030	1.051	1.161	0.985	1.027	1.109
1.095	1.119	1.205	1.089	1.111	1.172	0.988	1.108	1.162
1.222	1.334	1.438	1.209	1.304	1.370	0.994	1.200	1.303
1.250	1.355	1.464	1.223	1.331	1.375	0.997	1.217	1.345
1.296	1.428	1.555	1.242	1.390	1.505	1.000	1.224	1.398

Conclusion

The experimental results obtained for the discharge coefficients and the flow magnification factors generally, increase with decrease in crest radii and inclined angles. Therefore, the model with inclined angle of $\alpha=30^0$ and crest radius R=2.5cm performed best than the rest of the models. These findings are in good agreement with that of Baghei *et al.* (2003), Bhzad and Tahssen (2005), Thair and Tahssen (2006) and Kabiri-Samani *et al.* (2010).

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