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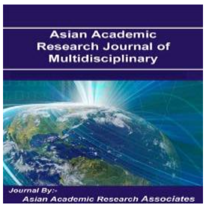

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CORRELATION BETWEEN CRITICAL OVERFLOW, DEPTH RATIO AND FROUDE NUMBER IN BROAD-CRESTED WEIR

J. G. EGBE[1]; E. E. NYAH[2]; S. E. UBI[3]; O. O. EWA[4]; E. E. OKON[5]

[1,2,3,4,5] Civil Engineering Department, Cross River University of Technology, Calabar, Nigeria

Abstract

Experiments were carried out in order to investigate the correlation between broad-crested weir overflow discharge, depth ratio and Froude number. The experiments were carried out on the horizontal open channel provided in the fluid mechanics/hydraulic laboratory of the Cross River University of Technology, Calabar- Nigeria. The experiment results show that the overflow depth above the weir crest or critical depth y_c increases as discharge increases. y_c, $y_{c,cal}$ and $y_{c,theory}$ are in very close agreement. Irrespective of overflow discharge rate, depth ratio and Froude number remain constant with values of 1.50 and 1.0 respectively. The overflow Froude number of unity ($F_{rc}=1$) shows that the flows were critical. For this weir, the relationship between Critical overflow and Critical Depth as

$Q_c = -1.7968 + 417.68y_c$ with $R^2 = 0.9994$.

INTRODUCTION

Weirs are ancient river barriers used as measuring and/or passage devices. Their existence is as a result of the quest for accurate measurement of flowing liquids. Paul Harrawood (1956) defined a weir as a regular bulkhead or dam or weir can be likened to an orifice with overflow liquid surface under atmospheric pressure. Weirs can serve as measuring, water storage, regulation and supplying devices. Weirs can be commonly found in different shapes and forms. Broad-crested weirs are those in which the water sheet flowing over the weir crest is less than twice the length of the weir. the weir overflow discharge per unit width as:

$$q = \frac{2}{3} C_d \sqrt{2g} H^{3/2}$$

Weirs can be commonly found in different shapes and forms. Broad-crested weirs are those in which the water sheet flowing over the weir crest is less than twice the length of the weir. (Leutheusser and Birk (1991), and Leutheusser and Fan (2001). The results of study of broad-crested weirs with a square upstream edge by Govinda Rao and Muralidhar (1963) show h/L ratio ranginging from 0.02 to 1.9 and h/P from 0.1 to 0.9, but with C_d persistently higher than those obtained by Bazin. This paper used experiments Correlation between critical Overflow, Depth ratio $\frac{\text{weir crest depth}, y_o}{\text{Critical Depth}, y_c}$, and Froude Number in Broad-Crested Weir.

METHOD

A. Experimental Work

1.) Specimens

a. Weir (25 x 75 x 114mm steel tablet)

3 replaceable steel tablets (3.1.1 25 x 75 x 114mm). During the experiment, the tablets were placed 2.5m away from the channel outlet to create a broad crested weir 0.075m wide, 0.114m long and 0.075m high. The weir generates and maintains the critical flow conditions required. Froude number obtained during the experiments varied from 0.032 to 1.00.

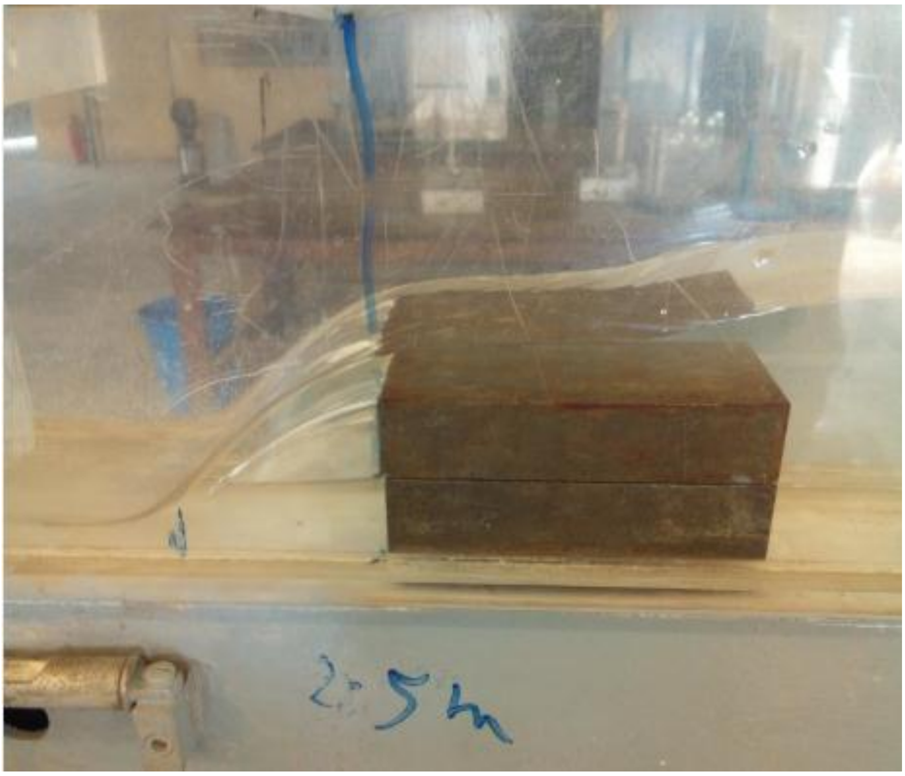
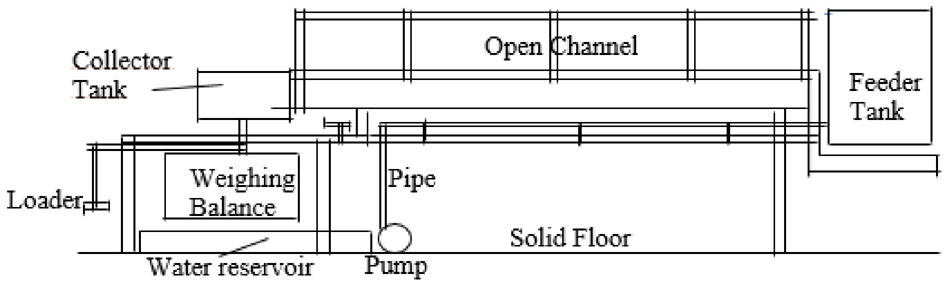


Fig. 1: Sample Weir Overflow

2. Experimental Test Set Up

The experiments were done on the horizontal open channel provided in the fluid mechanics/hydraulic laboratory of the Cross River University of Technology, Calabar-Nigeria. The channel dimensions are 0.075m (75mm) wide, and 0.15m (150mm) deep and 5.0m (5000mm) long. The channel is powered by a 1.13 KW (2 horse power) pump. It has an inlet feeder tank, braced smooth plexiglass perimeter base and walls and rubber packed sluice gate at the outlet. A constant head feeder tank provides the required discharge values and a pipe with a flow valve is used to regulate the discharge. Measurement of water depths is performed using a mobile point gage attached to the channel. The flow velocity at any point is measured using stopwatch to time floating cocks (expanded polystyrene beads). The average of three timings gives the flow velocity value at any section. For all the experiments, the weir is considered to be broad-crested since the overflow is less than twice the longitudinal length of the weir (i.e. y_c is less than 2 x 0.114m). Schematic view of the channel setup is given in fig. 2 and 3 below.



Gravinometric Open Channel Apparatus

Fig. 2.: Genal Set Up View

Fig. 3: View of The Open Channel in the hydraulic laboratory of the Cross River University of Technology (CRUTECH), Calabar, Nigeria

3. *General Experimental Procedures*

1. General inspection of the channel condition.
2. Use 9 turns of the screw-jack near the channel outlet to adjust and provide a bed to a slope of 1:196.
3. Fill the reservoir full with water.
4. Placed the three tablets 2.5m away from the channel outlet to create a broad crested weir 0.075m (75mm), 0.114m (114mm) long and 0.025m (25mm) high, with the weir tail corresponding to the 2.5m point of the channel.
5. Remove the sluice gate, supply and run a constant water head through the channel.
6. Adjust the flow valve to increase flow until the overflow depth above the weir crest or critical depth y_c is constant. The overflow obtained is critical.
7. Observe and measure relevant parameters.
8. Repeat the experiment by increasing flow for at least 5 different critical flows.

B. Theory

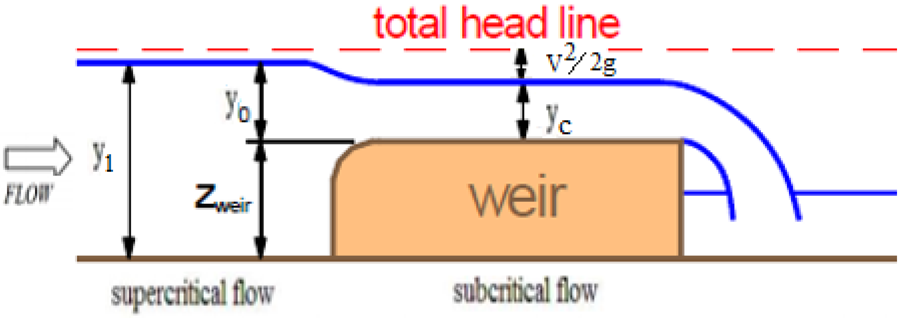


Fig. 5: Flow Over a Broad-Crested Weir

Assuming no loss of head,

$$H_{weir} = y_1 = Z_{weir} + y_o = Z_{weir} + y_c + \frac{v^2}{2g}$$

(1)

Notation

b = channel width = 75mm = 0.075m

$q = Q/b$ (m^2/s) = discharge per unit width

Z = weir depth (tablet thickness) in meters

v_1 = measured flow velocity upstream of weir

Q_1= discharge upstream of weir

y_1 = measured water depth upstream of weir

y_o = measured difference between water depth upstream of weir and weir height

$= (y_1 - Z)$ (2)

y_c = measured critical depth for minimum energy or overflow depth

$y_{c,cal}$= calculated critical depth for minimum energy = $2/3y_o$ (3)

$y_{c,theory}$ = theoretical critical depth for minimum energy = $\sqrt[3]{\frac{\left(Q/b\right)^2}{g}} = \sqrt[3]{\frac{(q)^2}{g}}$ (4)

v_c = Critical velocity of flow = $\frac{Q}{by_c}$ (5)

g = 9.806 m/s^2

III. RESULTS AND DISCUSSIONS

Table 1: General Experimental Data

		Upstream of Weir			Weir Overflow		
1	2	3	4	5	6	7	8
Flow	Z (m)	y_1 (m)	V_1 (m/s)	Q_1 x 10^{-4} (m^3/s)	y_c (m)	V_c (m/s)	Q_c x 10^{-4} (m^3/s)
1	0.075	0.089	0.030	2.00	0.009	0.30	2.00
2	0.075	0.093	0.046	3.20	0.012	0.35	3.20
3	0.075	0.096	0.056	4.00	0.014	0.37	4.00
4	0.075	0.104	0.078	6.09	0.019	0.43	6.09
5	0.075	0.104	0.078	6.20	0.019	0.43	6.20
6	0.075	0.105	0.084	6.53	0.020	0.44	6.53
7	0.075	0.105	0.085	6.60	0.020	0.44	6.60
8	0.075	0.111	0.108	9.00	0.024	0.49	9.90

Column 5 and 8 shows approximately equal discharge as a result of flow continuity. The overflow depth above the weir crest or critical depth y_c increases as discharge increases.

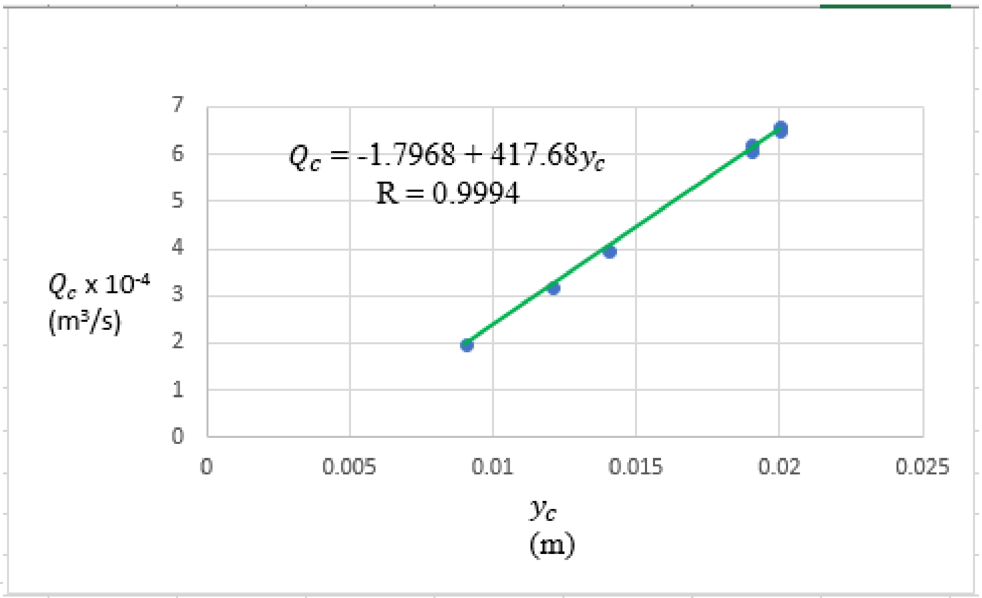


Fig. 6: Critical overflow vs. Critical Depth

Fig. 6 shows that for this weir, the relationship between Critical overflow and Critical Depth as Q_c = -1.7968 + 417.68y_c with $R^2 = 0.9994$. As critical overflow increased, critical depth increased.

Table 2

	Flow Depths					**Froude Number**		
Flow	y_o (m)	y_c (m)	$y_{c,cal}$ (m)	$y_{c,theory}$ (m)	$\frac{y_o}{y_c}$	F_{r1}	F_{rc}	Boundaries
1	0.014	0.009	0.009	0.009	1.50	0.032	1.00	$F_r > 1$ Supercritical flow
2	0.018	0.012	0.012	0.012	1.50	0.048	1.00	
3	0.021	0.014	0.014	0.014	1.50	0.057	1.00	
4	0.029	0.019	0.019	0.019	1.50	0.077	1.00	$F_r = 1$ Critical flow
5	0.029	0.019	0.019	0.019	1.50	0.077	1.00	
6	0.030	0.020	0.020	0.020	1.50	0.083	1.00	
7	0.030	0.020	0.020	0.020	1.50	0.083	1.00	$F_r < 1$ Subcritical flow
8	0.036	0.024	0.024	0.024	1.50	0.103	1.00	

Table 2 shows y_c, $y_{c,cal}$ and $y_{c,theory}$ are in very close agreement. Irrespective of overflow discharge rate, $\frac{\text{weir crest depth}, y_o}{\text{Critical Depth}, y_c}$ ratio and overflow Froude number are constant with values of 1.50 and 1.0 respectively. The overflow Froude number of unity (F_{rc}=1) shows that the flows were critical.

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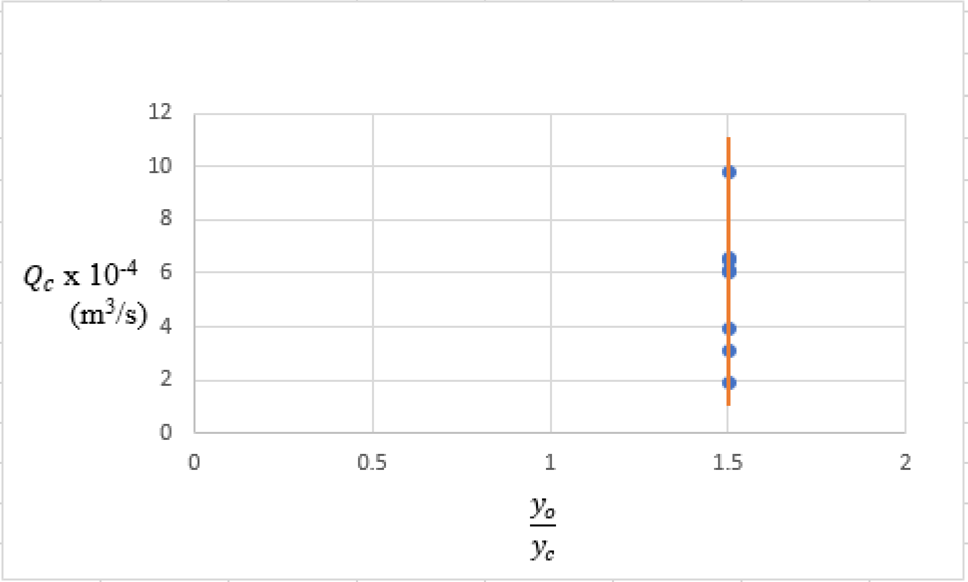

Fig. 7: Critical Overflow vs. Dimensionless Depth

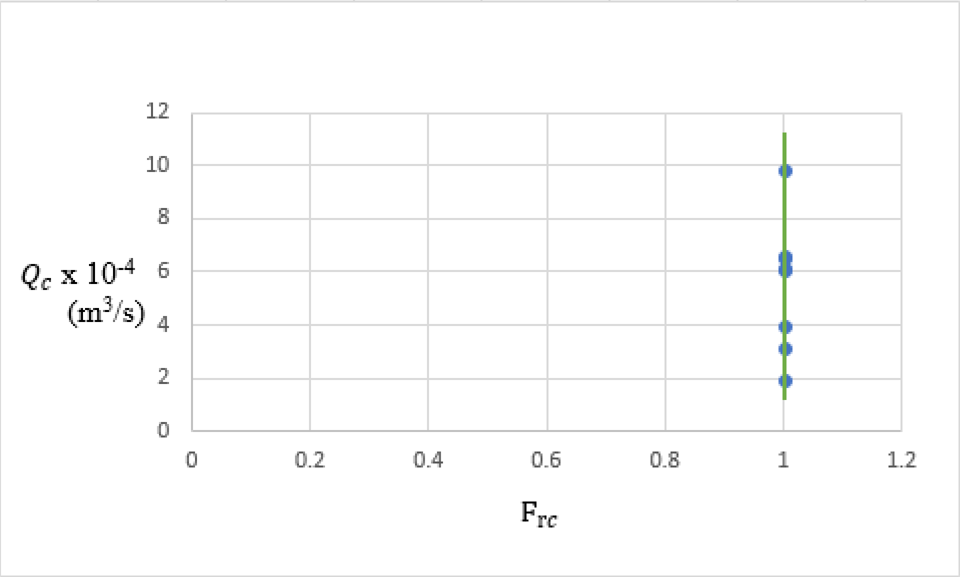

Fig. 8: Critical Overflow vs. Overflow Froude Number

Conclusions

From the work done, the following results were obtained:

1.) The overflow depth above the weir crest or critical depth y_c increases as discharge increases.

2.) y_c, $y_{c,cal}$ and $y_{c,theory}$ are in very close agreement.

3.) Irrespective of overflow discharge rate, $\frac{\text{weir crest depth}, y_0}{\text{Critical Depth}, y_c}$ ratio, Froude number remain constant with values of 1.50 and 1.0 respectively.

4.) The overflow Froude number of unity (F_{rc}=1) shows that the flows were critical.

5.) For this weir, the relationship between Critical overflow and Critical Depth as

Q_c = -1.7968 + 417.68y_c with $R^2 = 0.9994$.

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