Evaluation of Unsteady Open Channel Flow Characteristics over Crump Weir

By

Sani Yakubu Khalifa and Abdullahi Umar
Department of Water Resources and Environmental Engineering,
Ahmadu Bello University Zaria,
Email: khalees2k1@gmail.com, khalees2k@yahoo.com

ABSTRACT

A crump weir is commonly used to measure discharge in open flow channels. The laboratory test was conducted on six crump weir models of different apex angles 80°, 90° 100°, 110° 120° and 130°. Also by decreasing upstream angles to have the following values 85°, 70°, 55°, 40°, 25° and 10°. The increasing values of the downstream angles are 15°, 20°, 25°, 30°, 35° and 40° respectively to obtain the sum angle of triangle to be 180°. Plywood of thickness 22mm was used for fabricating the main body of the crump weir. This study comprises of laboratory work of physical model of crump weir based on unsteady open channel flow. It is therefore, concluded that, the weir model equation developed by linear combination method can suitably be used to compute discharge over the crump weir models with high precision and accuracy than the normal V-notch models. The larger the apex angle of the crump weir the more accurate will be in discharge estimation. From the result obtained model 6 is the most efficient crump weir having the least C_d of 1.15042 and least percentage error of 13.07552. And has best performance based on dependence of Q_o on h_o with 98.4%. Model 6 has apex angle of 130° upstream angle of 10° and the downstream angle of 40°.

INTRODUCTION

Many important transfer phenomena take place near the interface between air and water in the rivers, sea and lakes. Gas, chemicals, heat can be transferred in both directions depending also on turbulence level near the interface. Several attempts to quantify the effects of the free surface on turbulence have been successfully completed using numerical methods and experimental techniques, but no attention has been paid to the effects of turbulence on the free surface elevation (Herschy, 1978).

Compared with sharp-crested or broad-crested weirs, a Crump weir is a relatively long, gently sloped obstruction rising from the channel bottom. Some of the advantages of this weir are that it is less prone to develop a “dead-zone” ahead of the weir, accurate flow measurements are possible with the weir completely submerged, and the long downstream slope acts as an integral energy dissipater.

The flow measurement over the Crump weir is primarily dependent on the head (h_1), measured from the crest (where the fluid flows over the weir) to the surface of the stream at a distance of about 3*Ps upstream from the weir crest (where the surface elevation is not affected by the flow over the weir). It is also partly determined by whether the weir is submerged. Submergence is said to occur when the water surface elevation condition is

$$h_2 \geq {}^{3}/_{4}\, h_1 \qquad (1.0)$$

Under submerged conditions, a pressure head measurement is taken immediately after the crest and an additional correction is made to the basic flow computation.

The **crump weir** unit is designed to demonstrate the hydraulic conditions on an overflowed underwater weir, or incomplete overflow. Depending on the flow rate, subcritical or supercritical flow can be created, or upper rollers and hydraulic jumps can be observed and investigated.
The accessory unit is made of wood. It is designed for installation in the laboratory flow channel, to which it can be attached very easily.

FABRICATION OF THE EXPERIMENTAL MODELS

The experimental work was conducted on six crump weir models of different apex angles 80°, 90° 100°, 110° 120° and 130°. Also by decreasing upstream angles to have the following values 85°, 70°, 55°, 40°, 25° and 10°. The increasing values of the downstream angles are 15°, 20°, 25°, 30°, 35° and 40° respectively to obtain the sum angle of triangle to be 180°. Plywood of thickness 22mm was used for fabricating the main body of the crump weir.

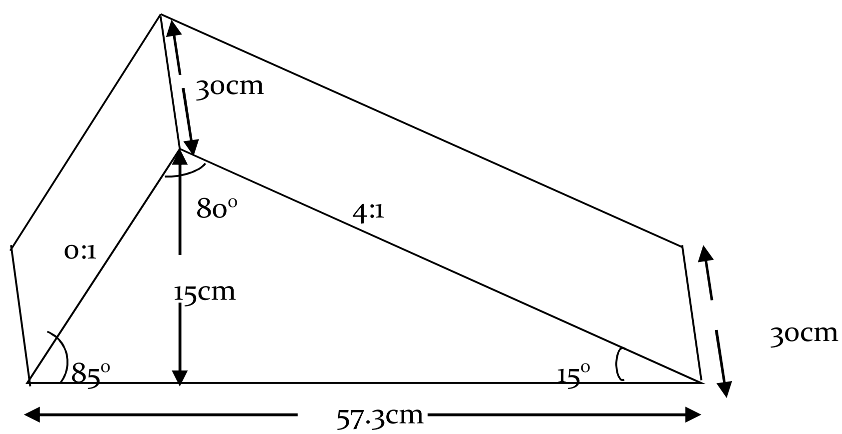


Figure 1: The schematic view of crump weir model 1 of apex angle 80°, upstream angle and slope, 85° and 0:1, downstream angle and slope, 15° and 4:1 respectively.

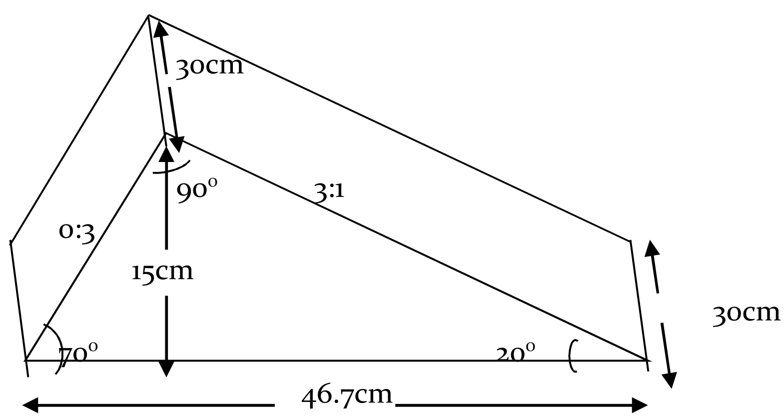


Figure 2: The schematic view of crump weir model 2 of apex angle 90°, upstream angle and slope, 70° and 0:3, downstream angle and slope, 20° and 3:1 respectively.

Table 1.0: Geometric Factors of Crump Weir Models

Model	Upstream Slope	Downstream Slope	Model width 'b' (cm)	Crest Height 'P' (cm)	Apex Angle (degree)	Upstream Angle(degree)	Downstream Angle(degree)
1	0:1	4:1	30	15	80	85	15
2	0:3	3:1	30	15	90	70	20
3	0:7	2:1	30	15	100	55	25
4	1:1	2:1	30	15	110	40	30
5	2:1	1:1	30	15	120	25	35
6	6:1	1:1	30	15	130	10	40

Plate I: Side view of the Tilting Flume

Plate II: Model 1 of apex angle 80°, upstream angle and slope, 85° and 0:1, downstream angle and slope, 15° and 4:1 respectively.

Plate III: Model 2 of apex angle 90°, upstream angle and slope, 70° and 0:3, downstream angle and slope, 20° and 3:1 respectively.

Plate IV: Model 3 of apex angle 100°, upstream angle and slope, 55° and 0:7, downstream angle and slope, 25° and 2:1 respectively.

Plate V: Model 4 of apex angle 110°, upstream angle and slope, 40° and 1:1, downstream angle and slope, 30° and 2:1 respectively.

Plate VI: Model 5 of apex angle 120°, upstream angle and slope, 25° and 2:1, downstream angle and slope, 35° and 1:1 respectively.

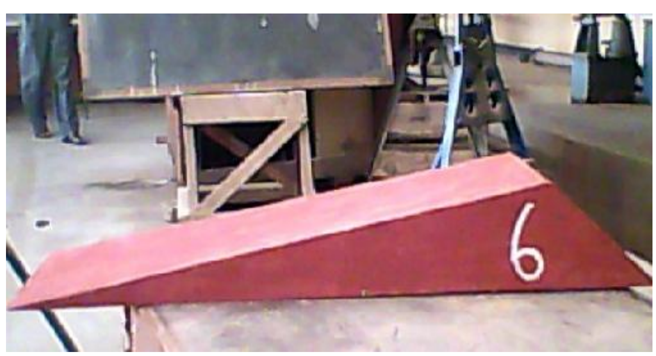


Plate VII: Model 6 of apex angle 130°, upstream angle and slope, 10° and 6:1, downstream angle and slope, 40° and 1:1 respectively.

EXPERIMENTAL PROCEDURE:

i. The crump weir was installed in the flume with the help of sealants to prevent leakage, which has to be levelled. One vernier was located downstream the weir and the other upstream. The verniers were zeroed with the bed of the channel.
ii. Six models were fabricated for which the angles were varied, 80^o, 90^o, 100^o, 110^o,120^o, and 130^o
iii. Experiment was then ran for each model and various heads and their corresponding discharges were recorded;
iv. The procedure has five (5) runs. Each run has a different flow rate and a set of four (4) y_o and y_1 depths; two sets for modular flow condition and the other two sets for non-modular flow condition.
v. The initial flow rate was set. Then, y_o and y_1 depths were recorded for the following conditions:
   a. Modular flow: without stop block (gate).
   b. Modular flow: one full stop block(gate) (y_1 should be the only depth that changes)
   c. Non-modular flow: Add a half of one stop block (gate). ($y_1$and y_o depth that change)
   d. Non-modular flow: Add one quarter of a stop block (gate).
   e. The flow rate will be increased at constant interval.
vi. The pump was activated and the discharge was adjusted using a control valve and the reading of the point gauge were recorded to give the head above crump weir required for the calculation of estimated discharge;
vii. At the beginning of each run the control valve was adjusted to alter the head;
viii. For each head recorded, the actual discharge was measured by direct method using the weighing arrangement provided at the tail end of the flume;
ix. The previous steps will be repeated for each of the seven runs of experiments to be conducted for each model.

Determination of Observed Discharge (Q_o)

The observed discharge, Q_o, was measured experimentally using the gravimetrical method. Throughout the experiment, 100kg of water were collected by means of the weighing balance (see plate II) attached to the flume and stopwatch was used to obtain the time taken to collect the 100kg for onward determination of discharge.

Volume, V = mass/density

Observed discharge, Q_o = Volume / average time

Average time = $(t_1 + t_2)/2$

Determination of Estimated Discharge (Q_e)

The discharge equation for the crump weir was used to compute the estimated discharge using the flow heads.

Point gauge will be used to measure the flow head (h) above the crump weir (Arora, 2005).

$$Q_m = C_d\sqrt{g}\,.bH_o^{\frac{3}{2}}\,. \quad (2)$$

$$C_d = 1.163\left(1 - \frac{0.0}{h}\right)^{1.5} \quad (3)$$

$$H = y + \frac{V^2}{2g} \quad (4)$$

$$f = Q/Q_m, \quad (5)$$

Accuracy of Discharge Measurement

In this study, the indicator employed to compare the accuracy of the crump weir models in measuring discharge is the average percentage error (E) expressed as:

$$E = \frac{1}{N} \sum_{i=1}^{N} \left| \frac{Q_o - Q_e}{Q_o} \right| \quad (6)$$

Where, N = number of experiments conducted per model

Q_o And Q_e are the observed and estimated discharges obtained for each run.

Discharge Coefficient

The discharge coefficients for simple rectangular and triangular weirs suggested respectively by French (1986) and Martinez et al. (2005) were adopted in this study. Expression for the global discharge coefficient (C_d) of the models was obtained by multiple regressions of the variables (i.e. h/P, C_d, and b).

In order to validate the suitability of the theoretical equations, the maximum of the absolute value of the deviation of the data from the model was obtained as:

$$MaxErr = max(abs(C_{do} - C_{de})) \quad (7)$$

Where, C_{do} = Experimental Discharge Coefficient = Q_o / Q_e

C_{de} = Estimated Discharge Coefficient

RESULT

Table 4.4: Summary of models performance

Model 1	θ_A	θ_u	θ_d	Range of Q_o (l/s)	Range of Q_e (l/s)	Average C_d	E (%)	Rank
M	80°	85°	15°	6.781 –8.228	5.881 – 7.128	1.1535823	13.31354	6
M	80°	85°	15°	6.781 –8.228	5.881 – 7.128	1.1535823	13.31354	
NM	80°	85°	15°	6.781 –8.228	5.879 – 7.123	1.1544512	13.378726	
NM	80°	85°	15°	6.781 –8.228	5.877 – 7.121	1.1547444	13.400718	
Average C_d =1.15409 13.35163 Model 2								
M	90°	70°	20°	4.644 – 7.813	4.033 – 6.775	1.1523054	13.217434	5
M	90°	70°	20°	4.644 – 7.813	4.033 – 6.775	1.1523054	13.217434	
NM	90°	70°	20°	4.644 – 7.813	4.032 – 6.770	1.1526534	13.243622	
NM	90°	70°	20°	4.644 – 7.813	4.032 – 6.769	1.1528126	13.255592	
Average C_{do} = 1.152519 13.23352 Model 3								
M	100°	55°	25°	4.601 – 6.110	4.000 – 5.301	1.151177	13.132336	3
M	100°	55°	25°	4.601 – 6.110	4.000 – 5.301	1.151177	13.132336	
NM	100°	55°	25°	4.601 – 6.110	3.997 – 5.300	1.1518974	13.186692	
NM	100°	55°	25°	4.601 – 6.110	3.996 – 5.299	1.1522564	13.213748	
Average C_{do} = 1.151627 13.16628								

Ranking is based on the closeness of average C_d to unity and also on the minimum average percentage error (E)

Table 4.5: Summary of models performance based on dependence of Q_o on h_o

Model 4	θ_A	θ_u	θ_d	Range of Q_o (l/s)	Range of Q_e (l/s)	Average C_{do}	E (%)	Rank
M	110°	40°	30°	5.000 –5.941	4.348 – 5.154	1.1515268	13.158724	4
M	110°	40°	30°	5.000 –5.941	4.348 – 5.154	1.1515265	13.158724	
NM	110°	40°	30°	5.000 –5.941	4.346 – 5.153	1.1518744	13.18493	
NM	110°	40°	30°	5.000 –5.941	4.345 – 5.152	1.152107	13.20247	
Average C_{do} = 1.151759 13.17621 Model 5								
M	120°	25°	35°	4.967 – 6.098	4.322 – 5.292	1.1506522	13.092692	2
M	120°	25°	35°	4.967 – 6.098	4.322 – 5.292	1.1506522	13.092692	
NM	120°	25°	35°	4.967 – 6.098	4.321 – 5.291	1.1509386	13.114328	
NM	120°	25°	35°	4.967 – 6.098	4.319 – 5.291	1.1512122	13.134966	
Average C_{do} = 1.150864 13.10867 Model 6								
M	130°	10°	40°	4.800 – 6.263	4.178 – 5.440	1.1501978	13.058384	1
M	130°	10°	40°	4.800 – 6.263	4.178 – 5.440	1.1501978	13.058384	
NM	130°	10°	40°	4.800 – 6.263	4.177 – 5.438	1.1505050	13.081594	
NM	130°	10°	40°	4.800 – 6.263	4.175 – 5.437	1.1507776	13.103700	
Average C_{do} = 1.15042 13.07552								

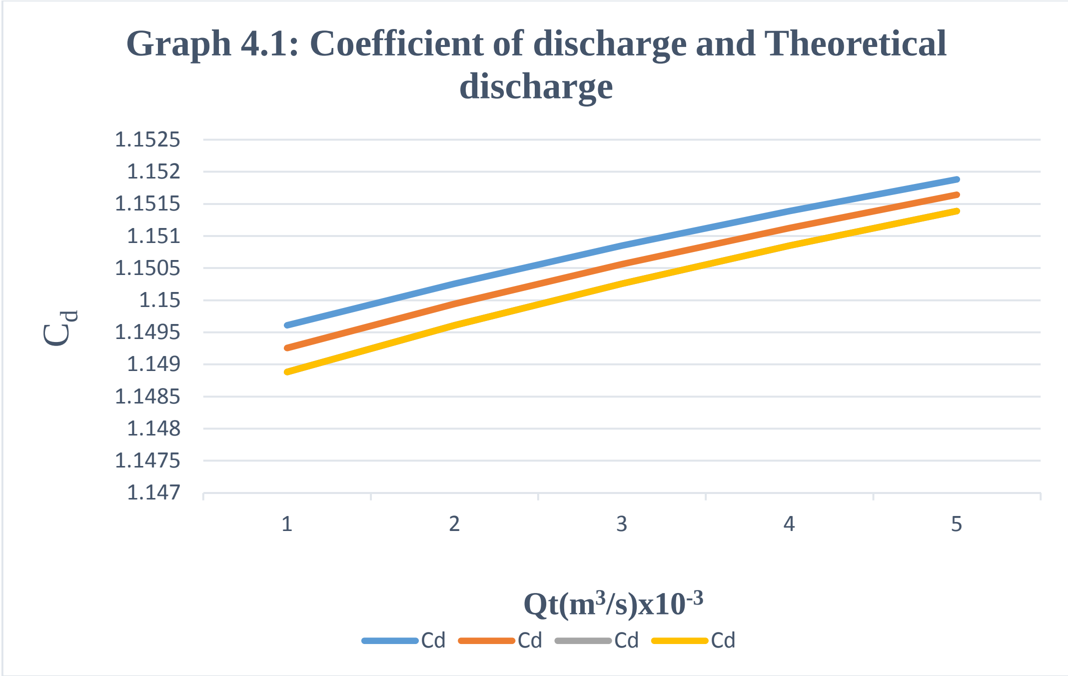
The ranking is based on strong dependence of discharge on the upstream water head above crest

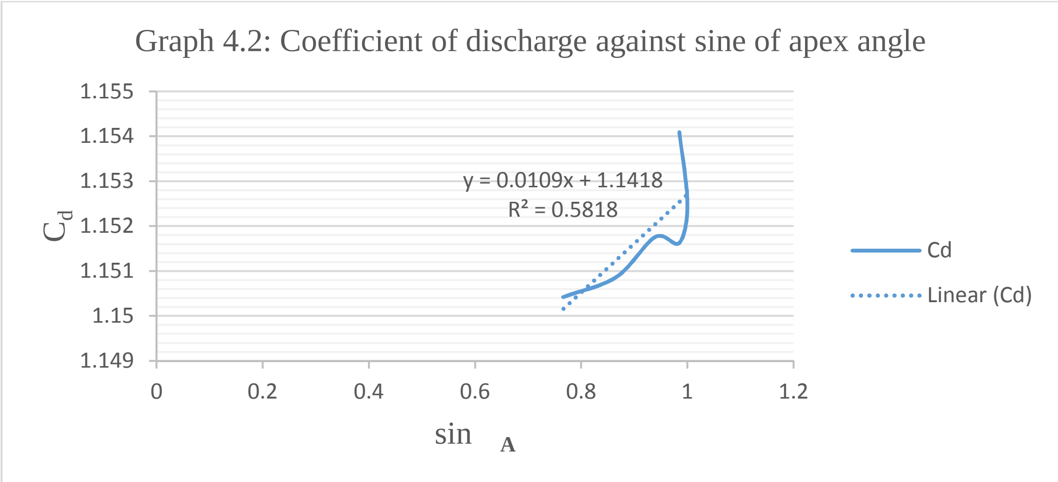
Model	**R^2**	**%**	**Ranking**
1	0.831	83.1	5
2	0.870	87.0	4
3	0.674	67.4	6
4	0.873	87.3	3
5	0.879	87.9	2
6	0.984	98.4	1

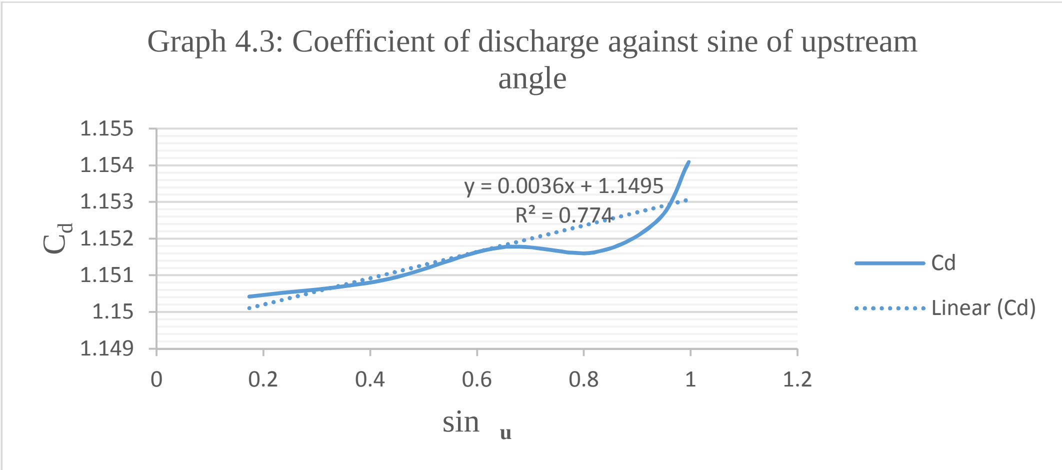
Table 4.6 Summary of models Characteristics θ_d

Model	Upstream Slope	Downstream Slope	Model width 'b'(cm)	Crest Height 'P' (cm)	θ_A	θ_u	θ_d	C_d	sin θ_A	sinθ_u	sin θ_d
1	0:1	4:1	30	15	80	85	15	1.15409	0.9848	0.9962	0.2588
2	0:3	3:1	30	15	90	70	20	1.152519	1.0000	0.9396	0.3420
3	0:7	2:1	30	15	100	55	25	1.151627	0.9848	0.8192	0.4226
4	1:1	2:1	30	15	110	40	30	1.151759	0.9396	0.6428	0.5000
5	2:1	1:1	30	15	120	25	35	1.150864	0.8660	0.4226	0.5735
6	6:1	1:1	30	15	130	10	40	1.15042	0.7660	0.1736	0.6428

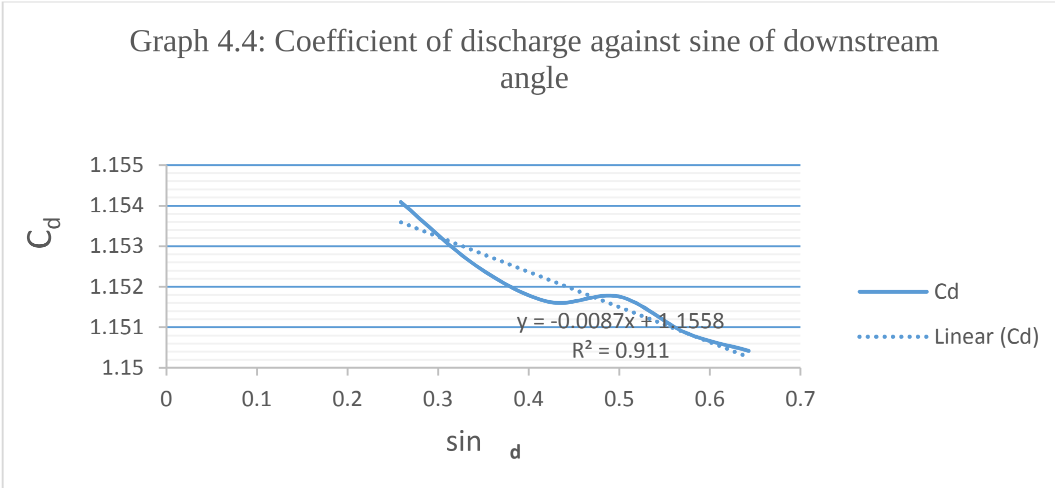
$C_d = 1.159 - 0.0000662\ \theta_A$, $R^2 = 0.874$







The frictional loss along the weir as well as wetness of the plywood of the weir are minimized by painting the weir to smoothen the surface.



CONCLUSION

Based on the results of the investigation, the following conclusions are reached:

1. The coefficient of discharge C_d increases with an increase in flow rate.
2. Model 1 yield the highest flow rate and model 4 yield the lowest. The flow rate decreases from model 1 to model 3 and increases from model 4 to model 6.
3. The flow rate decreases from modular to non-modular flow conditions for each model.
4. C_d increases from modular to non-modular conditions for each model.
5. C_d decreases from model 1 to model 6 with model 6 having the least C_d close to unity and least percentage error making model 6 to be more efficient.
6. The higher the apex angle, the lower the upstream angle and the higher the downstream angle the more efficient a crump weir will be.
7. From table 4.5, the result shows that model 6 has the highest discharge –upstream depth above crest dependence of 98.4% making it to be more efficient.
8. From graph 4.2-4.4 the result shows that downstream angle, $\boldsymbol{\theta_d}$ is strongly related with C_d by 91.1%, followed by $\boldsymbol{\theta_u}$ with 77.4% and $\boldsymbol{\theta_A}$ with 58.18%. Therefore downstream angle is more influential for crump weir in controlling erosion.
9. The flow at upstream is sub critical and super critical at downstream. Specific energy also decrease when the flow over a crump weir and increased when the flow passing the weir.
10. Generally, the pattern of flow over a crump weir shows that it has changed from sub critical to supercritical flow for different flow rates values.
11. Energy dissipated during hydraulic jump will cause power dissipated. Power dissipated depends on the flow rate, energy dissipated and other hydraulics criteria.
12. The results shows that the weir discharge coefficient is dependent on the upstream angle, apex angle and downstream angle of the weir. As the upstream angle decreases from 85^o to 10^o, apex angle increases from 80^o to 130^o and downstream angle increases from 15^o to 40^o the weir discharge coefficient is decreasing.

REFERENCES:

Arora K. R. (2005). *Fluid mechanics and hydraulic machines.* Standard publishers Distributors, 1705-B Nai Sarak, Post Box No.: 1066, Delhi-110006.

Barr, J., (1910). *Experiments upon the flow of water over triangular notches*. Engineering (London)

Bengtson Harlan (2010). *Open channel flow measurement*. Bright hub. Retrieved March 6, 2011, from http://www.brighthub.com/engineering/civil/articles/65701.aspx

Bos, M.G. (1985). *Discharge measurement structures.* International Institute for Land Reclamation and Improvement (ILRI), publication 20, Wageningen, The Netherlands.

Chanson, H. (2004). *The hydraulics of open channel flow: an introduction*. Butterworth-Heinemann, Oxford, UK, 2nd edition. Retrieved March 6, 2011, from http://www.wikipedia.com

Civil Engineering Series. Page; 1-24, 325-365, 393-365.

Greve, F. V. (1932). *Flow of water through circular, parabolic and triangular vertical notch weirs.* Purdue Univ. Eng. Bull., 16, No. 2, Res. Series 40

Herschy R. W. (1978), *Hydrometry principles and practices.* Department of the Environment Water Data Unit; Reading, A Wiley – Interscience Publication, John Wiley and Sons

Hertzler, R. A. (1938). *Determination of a formular for the 120° V-notch weir*. Civil Engineering, 756.

Jan Chyan-Deng, Chia-Jung Chang, and Feng-Hao Kuo (2009), Experiments on Discharge Equations of Compound Broad-Crested Weirs. *Journal of Irrigation and Drainage Engineering © Asce / July/August 2009 / 511*

Jan Chyan-Deng, Chia-Jung Chang, and Ming-His Lee (2006), Discussion of Design and calibration of compound sharp-crested weir by J. Martinez et al. *Journal of Hydraulic Engineering, 132(8), 868–871.*

King, H. W. (1916). *Flow of water over right-angled V-notch weir.* Univ. Mich. Technic. 29, No. 3, 189

Lenz, A. T., (1943). *Viscosity and surface tension effects in V-notch weir coefficients.* Trans. A.S.C.E., 108

Martinez J., Reca J., Morillas M. T., and López J. G.; (2005), Discussion of Design and Calibration of a Compound Sharp-Crested Weir. *Journal of Hydraulic Engineering © ASCE Vol. 131, No.2, pp. 112-116.*

Piratheepan M., Winston N.E.F., and Pathirana K.P.P. (2006), Discharge measurements in open channels using compound sharp-crested weirs. *Journal of the Institution of Engineers, Sri Lanka Vol. xxxx, No. 03, pp.31-38.*

Richard H. French (1985), *Open-Channel Hydraulics*. Mc Graw Hill, New York.

Shen, J. (1960). *Discharge characteristics of triangular-notch thin-plate weirs.* U.S. Dept. of Interior, Geological Survey, draft for I.S.O.

Simon A. L. (1976). *Practical hydraulics.* John Wiley and Sons, Inc. New York. London. Sydney. Toronto.

Sturm, T.W. (2001). *Open Channel Hydraulics.* McGraw Hill, Boston, USA, Water Resources and Environmental Engineering Series, 493 pages.

Vasudevan N., Hemalatha K., Walter D. and Thanasekaran K. (2008). *Feasibility studies on the impact of bioremedial processes in contaminated urban lake environments.* Centre for Environmental Studies Anna University, Chennai 600 025, Email: nvasudevan@annauniv.edu

