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Calibration of Compound Weirs

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Abstract : This research describes the design and calibration of compound sharp crested (CSC) and compound broad crested (CBC) weirs, consisting of the combination of rectangle, triangle, and trapezoidal shapes. To improve the accuracy of the measurement of the coefficient of discharge of the flow, compound weirs are made up of two regular weir types combined together to form a single weir. A linear combination is developed to illustrate the discharge equation for the compound shapes of the sharp-crested as well as the broad-crested weirs using the standard discharge equations for basic rectangular and triangular weirs that already exist. Weir crest and weir height on the upstream side of the weir are two elements to take into consideration when calibrating compound weirs to determine the coefficient of discharge (Cd). The experimental analytical work was carried out in a laboratory, and from that determination, the coefficient of discharge was calculated for the available compound shapes of the weirs. To validate the analytical results of newly developed weirs, experimentation was carried out in laboratory on hydraulic flume, From the readings noted, Coefficient of discharge (Cd) was calculated for the compound weirs. Different geometries (the combination of shapes and height of the weirs) were tested in order to validate the results of the research and to establish the head-discharge relationship for various compound shapes of weir.

***Index Terms* - Compound Weir, Sharp-crested weir, Broad-crested weir, Coefficient of discharge.**

I. INTRODUCTION

A weir is an obstruction across a river or stream's width that regulates the water's flow characteristics. Weirs are commonly used to regulate water flow, raise water levels, and keep track of the quantity of water is being used in a certain catchment region. Sharp-crested and broad-crested weirs are the two main categories. A clear, distinct transition between the upstream and downstream water surface levels is caused by sharp crested weirs, which have a sharp or thin edge. Since their crests are wider, broad crested weirs result in fewer apparent transition zones. Due to the lack of suitable water resources, flow measurement in hydraulic flumes, water and wastewater systems, and irrigation and drainage networks is important for the various flow measurements. A weir is a low-head dam which is constructed across a river to control the flow and discharge of water. Theoretical equations are to be used for calculating the coefficient of discharge of the flow of water, and this is done in the laboratory and cast-in-situ as well. In this regard, some equations have been theoretically developed and calibrated using experimental data. For experimental validation and determination in the laboratory, the triangular and rectangular weirs are used to calculate the coefficient of discharge of water.

A compound weir is a hydraulic structure that consists of two or more type of weir shapes combined into one structure to increase the discharge capacity. However, in many situations, such as irrigation canals with large variations in flow discharges, the selection of either a rectangular or triangular weir is erroneous or unsafe[2]. For this reason, compound sharp crested and compound broad crested weirs have been recently designed and implemented to increase the accuracy in measurement and avoid the various losses are occurred due to surrounding conditions. A compound weir is a composition of two standard shapes of weir to form a new shape, such as the combination of triangular and rectangle-shaped weirs. This provides good measurements for the stream with a wide range of flows. The discharge over a compound weir is calculated by simply applying the standard discharge equation for each segment of the weir to the head on that segment of the weir. The total discharge is then the sum of the discharges of each segment of the weir. These studies have been carried out on CRRSC, CTRSC, and CRT_zSC for sharp crested weirs and CRRBC, CTRBC, and CRT_zBC for broad crested weirs. J. Martinez et al. (2005) developed and calibrated an equation for discharge measurement of the compound sharp-crested weir. Chyan-Deng Jan et al. (2009) developed and calibrated an equation for discharge measurement of compound broad crested weirs.

II. SIMPLE WEIRS

To determine the coefficient of discharge for regular shapes of weirs (Rectangular and, Triangular) some theoretical equations are already described in many hydraulic books. The triangular and rectangular shapes of weirs as shown below (Photo 1):

(a)Triangular Weir

(b)Rectangular Weir

Photo 1: Simple shape weir

The discharge equation for rectangular sharp-crested weirs can be written as (Henderson 1966),

$$Q = \frac{2}{3} . C_{rd} . \sqrt{2g} \; . b. h^{3/2} \qquad \text{Eq. 1}$$

The discharge equation for triangular sharp-crested weirs can be written as,

$$Q = \frac{8}{15} . C_{td} . \sqrt{2g} \; . \tan(\frac{\theta}{2}) . h_e^{5/2} \qquad \text{Eq. 2}$$

Where, Q = discharge, g = acceleration due to gravity, h = water head over the weir crest, b = weir length, C_{rd} = discharge coefficient of rectangular sharp-crested weirs, C_{td} = discharge coefficient of rectangular sharp-crested weir, h_e = effective head, Θ = angle of triangular portion of weir.

Calculating the coefficient of discharge for rectangular sharp-crested weir, The weir height P , head on crest h, weir length b and channel width B are to be considered as described by French (1986)

$$C_{rd} = \frac{0.611+2.23(\frac{B}{b}-1)^{0.7}}{1+3.8(\frac{B}{b}-1)^{0.7}} + \frac{0.075+0.011(\frac{B}{b}-1)^{1.46}}{1+4.8(\frac{B}{b}-1)^{1.46}} . \frac{h}{p} \qquad \text{Eq. 3}$$

According to Bos (1976) for calculating the coefficient of discharge of triangular sharp-crested weir the following equation is used:

$$C_{td} = 0.6085 - 0.0525\Theta + 0.02135\Theta^2 \qquad \text{Eq. 4}$$

For calculating effective head of the weir (h_e) the following equation is to be followed ,

$$h_e = h + K_h \qquad \text{Eq. 5}$$

Where, K_h = correction head for calculating viscous and surface tension effects as shown in equation 6,

$$K_h = 3.9058 – 3.8558\Theta + 1.1940\Theta^2 \qquad \text{Eq. 6}$$

Where, Θ is considered in radian (1 rad = 57.2958°)

According to Bos (1976) some discharge equations are expressed foe calculating the coefficient of discharge for rectangular broad-crested weir are shown below:

$$Q = \frac{2}{3} . C_{DRB} . \sqrt{\frac{2g}{3}} . b. H_0^{3/2} \qquad \text{Eq. 7}$$

For simple triangular broad-crested weir Bos (1976) derived the discharge equation in the form below:

$$Q = \frac{16}{15}. C_{DTB} . \sqrt{\frac{2g}{5}} . \tan(\frac{\theta}{2}). H_0^{2.5} \quad \text{Eq. 8}$$

For a truncated triangle in broad crested weir Bos (1976) expressed equation as given below :

$$Q = \frac{2}{3}. C_{DRB} . \sqrt{\frac{2g}{3}} . b. (\frac{H0}{H})^{1.5} (H - \frac{1}{2}H_a)^{1.5} \quad \text{Eq. 9}$$

Where, Q = volumetric flow discharge, C_{DRB} = coefficient of discharge for rectangular weir, C_{DTB} = coefficient of discharge for triangular weir, g = acceleration due to gravity, b = width of the crest in transverse direction, Ɵ = angle of triangular portion of the weir, H_a = depth of the triangular part of the weir and H_0 = total energy head at the upstream measurement section that is for the referenced upstream water head H adding to its corresponding velocity as shown below,

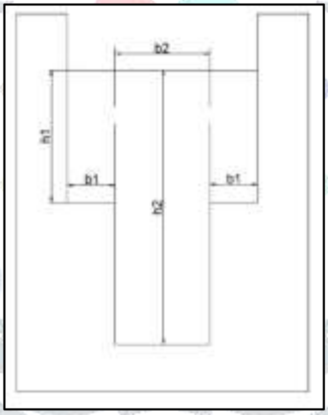
$$H_0 = H + (\frac{V0^2}{2g}) \quad \text{Eq. 10}$$

According to Bos (1976) for truncated triangle one condition are to be given for H_0 , i.e. H_0 should must larger than $1.25H_a$.

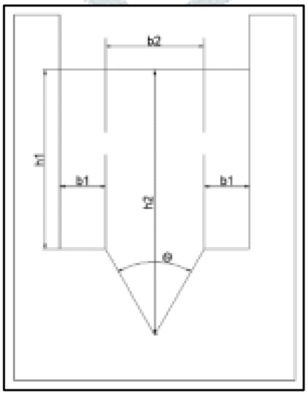
III. MATERIALS & METHODOLOGY

The compound weir is a hydraulic structure that consist of two or more shapes of weirs combined into one structure to increase the discharge capacity. Compound weirs are commonly used in situation where the available head is limited, but the required discharge is large.

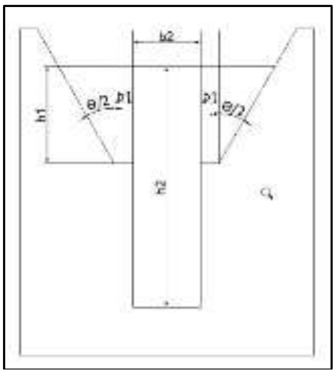
The three compound shapes of weirs are investigated in the present study for calculating the coefficient of discharge for both the types of weirs i.e. for sharp crested weirs and for broad crested weirs. They are combination of Rectangle-Rectangle (R-R), Triangle-Rectangle (T-R) and Rectangle-Trapezoidal (R-T_z) for sharp crested and for broad crested weirs respectively. The weirs were made with a thickness of 2mm Acrylic thin sheet. For sharp crested weir crest width is taken as 2mm and for broad crested weir is taken as 50mm for all shapes of weirs respectively.



(a)Compound Rectangle-Rectangle (CRR) weir



(b)Compound Triangle-Rectangle (CTR) weir



(c)Compound Rectangle-Trapezoidal (CRT_z) weir

Fig. 1: Cross-section of compound sharp & broad-crested weirs

Theoretical equations are to be derived by combining the simple equations and then derived the linear combinations of those simple equations, Jan et al. (2006) and Lee et al. (2012) proposed the following equations for R-R, T-R and, R-T_z for sharp-crested weirs, and Bos (1976) proposed the equations for broad-crested weirs.

$$Qth = \frac{2}{3} C_{rd1} .\sqrt{2g} .(2b_1). h_1^{1.5} + \frac{2}{3} .C_{rd1} .\sqrt{2g} .b_2 .h_2^{1.5}$$

……(CRRSC)[20] Eq. 11

$$Q_{th} = \frac{8}{15} . C_{td} . \sqrt{2g} . \tan(\frac{\theta}{2}). (h_{2e}^{2.5} – h_{1e}^{2.5}) + \frac{2}{3} .C_{rd1} .\sqrt{2g} .(2b_1).h_1^{1.5}$$

……..(CTRSC)[20] Eq. 12

$$Q_{th} = \frac{2}{3} C_{rd2} .\sqrt{2g} .b_2. h_2^{1.5} + \frac{2}{3} .C_{rd1} .\sqrt{2g} .(2b_1).h_1^{1.5} + \frac{8}{15} . C_{td} . \sqrt{2g} . \tan(\frac{\theta}{2}). h_{1e}^{2.5}$$

…….(CRT_zSC)[20] Eq. 13

$$Q_{th} = \frac{2}{3}. C_{DRB1} . \sqrt{\frac{2g}{3}} . (2b_1). H_{01}^{1.5} + \frac{2}{3}. C_{DRB2} . \sqrt{\frac{2g}{3}} . b_2 . H_{02}^{1.5}$$

…….(CRRBC)[12] Eq. 14

$$Q_{th} = \frac{2}{3}. C_{DRB} . \sqrt{\frac{2g}{3}} . (2b_1). H_{01}^{1.5} + \frac{2}{3}. C_{DRB2} . \sqrt{\frac{2g}{3}} . b_2. (\frac{H02}{H2})^{1.5} (H_2 - \frac{1}{2}H_a)^{1.5}$$

…….(CTRBC)[12] Eq. 15

$$Q_{th} = \frac{2}{3}. C_{DRB} . \sqrt{\frac{2g}{3}} . (2b_1). H_{01}^{1.5} + \frac{2}{3}. C_{DRB2} . \sqrt{\frac{2g}{3}} . b_2 . H_{02}^{1.5} + \frac{16}{15}. C_{DTB1} . \sqrt{\frac{2g}{3}} . \tan(\frac{\theta}{2}). H_{01}^{2.5}$$

……..(CRT_ZBC)[12] Eq. 16

Where, Qth = Theoretical discharge, g = acceleration due to gravity, b = width of the crest in transverse direction, h = water head over upper or lower parts of compound weirs, Ctd = discharge coefficient of simple triangular weir, Crd = discharge coefficient of rectangular sharp-crested weir, ϴ = angle of triangular portion of weir, C_{DTB} = coefficient of discharge for triangular broad-crested weir, C_{DRB} = coefficient of discharge for rectangular broad-crested weir, H_0 = total energy head at the upstream measurement section, h_e = effective head.

IV. EXPERIMENTAL ANALYSIS

Comparing the measured discharge with the calculated discharge with reference to the mentioned theoretical equation for water flows over a compound weirs, was conducted in a laboratory on the basis of the experiments. This is done for all combinations of the shapes of the weirs, i.e., R-R, T-R, and R-Tz. The experiments were conducted in a tilting bed flow channel (hydraulic flume), having a length of 4.7m long, is 15cm wide, and is 23cm deep. It is provided with a pointer gauge to determine the depth of the flow of water at any section of the flume. The control gates are provided at the upstream and downstream ends to control the flow. A measuring tank is used to measure the discharge flow through the flume with the help of stopwatch. The weirs are to be fitted in the flume to measure the coefficient of discharge of water.

Three runs of experiments were conducted for each of the three sharp-crested and broad-crested weirs. The geometrical parameters of the weirs i.e. weir length, weir width and weir height with reference to the available regular shapes of the weir. The experiments are conducted and later on determine the coefficient of discharge for all compound shapes of the weirs. For experimentation the channel width is 15.5cm and bed slope is maintain at 0.012 for all shapes of compound weir.

The hydraulic flume i.e. Tilting Bed Flow Channel is shown in photograph (2), on which we perform the testing of various shapes of compound weirs. The details of hydraulic flume is as discussed earlier.

Photo 2: Tilting Bed Flow Channel

The followings photographs (3 (a), (b), (c)) shows the position of compound weir specimens in tilting bed flow channel during the testing. The position of weir specimen kept vertical with sharp edge facing the upstream side.

(a)CRRBC Weir

(b)CTRBC Weir

(c)CRT$_z$BC Weir

Photo 3: Testing of weir specimen

V. RESULTS & DISCCUSION

The theoretical equations were used for the determination of the coefficient of discharge for all the combinations of compound shape weirs. The theoretical discharge for sharp-crest weirs ranges from 0.0011067 to 0.0037142 m^3/s while the actual discharge ranges from 0.0014505 to 0.0061081 m^3/s. The discharge variation for broad crested weirs for theoretical discharge ranges between 0.0019135 to 0.0088399 m^3/s, and the range for actual discharge varies between 0.0013447 to 0.0064204 m^3/s.

The following tables shows the experimental results for various shapes of compound weir.

Table 1 : Experimental Results for CRR sharp-crest weir

Run No.	Characteristics of compound Weirs						Discharge (m^3/s)		$C_d = \left(\frac{Q_{act}}{Q_{th}}\right)$
	b1 (cm)	b2 (cm)	h1 (cm)	h2 (cm)	Crd_1	Crd_2	Q_{th}	Q_{act}	
1	2.5	5	2.10	9.60	0.589	0.588	0.0028469	0.0031682	1.11
2	2.5	5	2.93	10.43	0.589	0.588	0.0033626	0.0048428	1.44
3	2.5	5	3.47	10.97	0.589	0.588	0.0037142	0.0061081	1.64
								Avg =	**1.40**

Table 2 : Experimental Results for CRR broad-crest weir

Run No.	Characteristics of compound Weirs						Discharge (m^3/s)		$C_d = \left(\frac{Q_{act}}{Q_{th}}\right)$
	b1 (cm)	b2 (cm)	h1 (cm)	h2 (cm)	Crd_1	Crd_2	Q_{th}	Q_{act}	
1	2.5	5	8.77	9.60	0.589	0.588	0.0066029	0.0031801	0.48
2	2.5	5	10.17	10.43	0.589	0.588	0.0074921	0.0034451	0.46
3	2.5	5	12.23	10.97	0.589	0.588	0.0088399	0.0064204	1.64
								Avg =	**0.56**

Table 3: Experimental Results for CTR sharp-crest weir

Run No.	Characteristics of compound Weirs						Discharge (m^3/s)		$C_d = \left(\frac{Q_{act}}{Q_{th}}\right)$
	b1 (cm)	Θ	h1 (cm)	h2 (cm)	Crd_1	Ctd	Q_{th}	Q_{act}	
1	2.5	60°	1.92	6.60	0.587	0.578	0.0011067	0.0014505	1.31
2	2.5	60°	3.02	7.77	0.587	0.578	0.0017024	0.0022346	1.31
3	2.5	60°	5.32	10.00	0.587	0.578	0.0030891	0.0036412	1.18
								Avg =	**1.25**

The Tables represents the experimental results for the different compound sharp crested & broad-crested weirs. The first column of the table represents the run number, next adjacent column represents the characteristics of compound weirs, the next proceeding column represent the discharge value i.e. actual discharge which is measured by volumetric method and theoretical discharge is calculated by the linear combinations of the equations for that compound weir as we discussed earlier. Last column shows the Coefficient of Discharge (Cd) for the particular shapes of compound weir and gives the average discharge value for the particular compound shapes of weir.

Table 4: Experimental Results for CTR broad-crest weir

Run No.	Characteristics of compound Weirs						Discharge (m^3/s)		C_d= $(\frac{Qact}{Qth})$
	b1 (cm)	ϴ	h1 (cm)	h2 (cm)	Crd_1	Crd_2	Q_{th}	Q_{act}	
1	2.5	60°	6.6	11.28	0.578	0.587	0.0019135	0.0013447	0.70
2	2.5	60°	8.73	13.41	0.578	0.587	0.0031190	0.0030987	0.99
3	2.5	60°	10.8	15.48	0.578	0.587	0.0040692	0.0050296	1.24
								Avg =	**0.97**

Table 5: Experimental Results for CRT_z sharp-crest weir

Run No.	Characteristics of compound Weirs							Discharge (m^3/s)		C_d= $(\frac{Qact}{Qth})$
	b1 (cm)	b2 (cm)	h1 (cm)	h2 (cm)	Crd_1	Crd_2	Ctd	Q_{th}	Q_{act}	
1	1	3.5	0.50	8.00	0.588	0.587	0.578	0.0013882	0.0019012	1.37
2	1	3.5	1.80	9.30	0.588	0.587	0.578	0.0018592	0.0024128	1.30
3	1	3.5	5.00	12.5	0.588	0.587	0.578	0.0037015	0.0037211	1.01
									Avg =	**1.22**

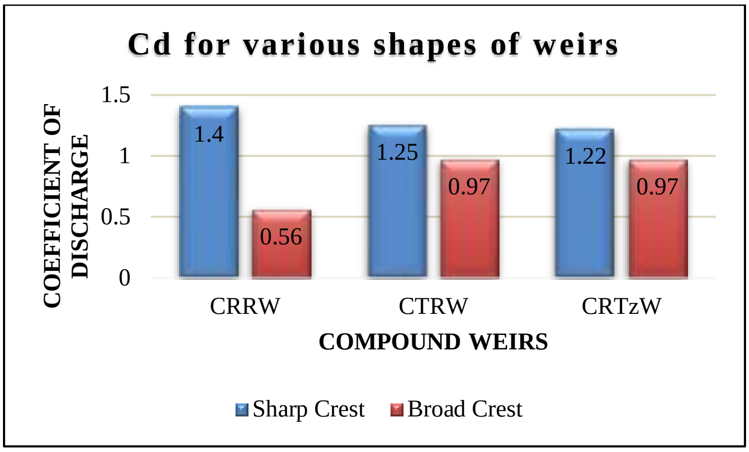
Table 6: Experimental Results for CRT_z broad-crest weir

Run No.	Characteristics of compound Weirs							Discharge (m^3/s)		C_d= $(\frac{Qact}{Qth})$
	b1 (cm)	b2 (cm)	h1 (cm)	h2 (cm)	Crd_1	Crd_2	Ctd	Q_{th}	Q_{act}	
1	1	3.5	8.69	16.19	0.588	0.589	0.578	0.0029100	0.0022705	0.78
2	1	3.5	10.69	18.19	0.587	0.589	0.578	0.0035720	0.0034416	0.96
3	1	3.5	12.09	19.56	0.587	0.590	0.578	0.0040627	0.0048290	1.18
									Avg =	**0.97**

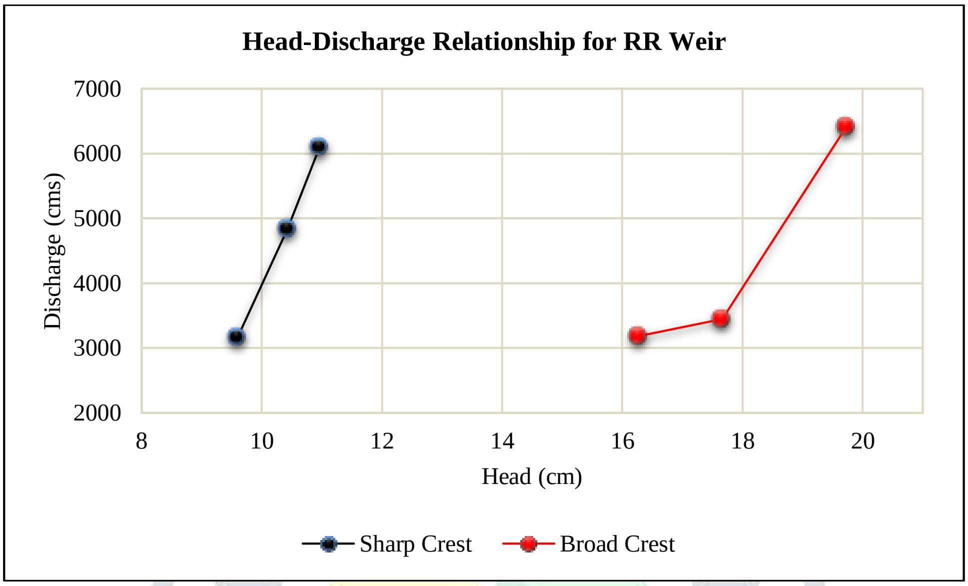
The ratio of the actual discharge and the theoretically calculated discharge is denoted by C_d (i.e. $C_d = Q_{act}/Q_{th}$). When theoretical discharge and experimental results compared, it has been observed that the discharge for compound sharp-crest weirs are approximately 8-10% higher than that for compound broad-crest weirs.

Compound weirs are generally used to control the discharge over canals, rivers, dams, etc. The following are some application of compound weirs that we are suggesting on basis of our research.

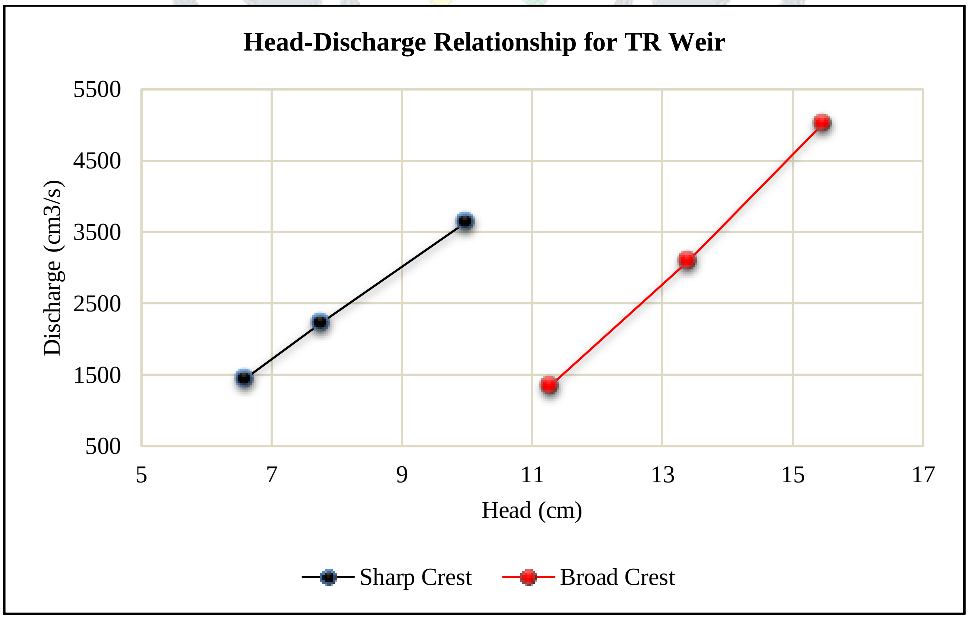
a) For the condition with low head and high discharge compound weir with Rectangle-Rectangle combination is suitable.
b) For the condition with low head and low discharge Triangle-Rectangle weir is suitable.
c) For the condition with low head and medium discharge Rectangle-Trapezoidal weir are recommended.



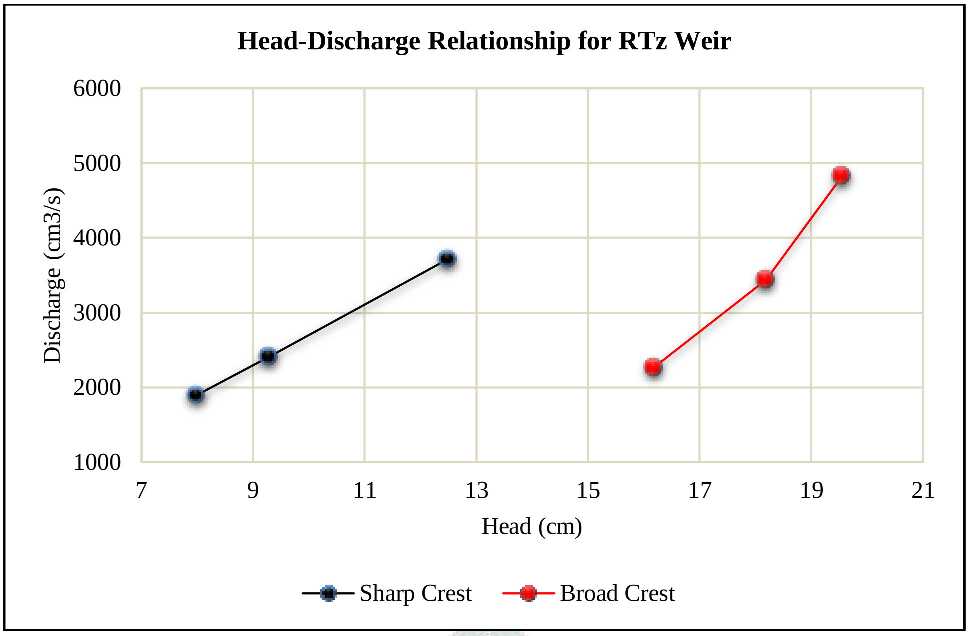
Graph 1: Coefficient of discharge (C_d) for various shapes of weir



Graph 2: Head-Discharge Relationship for RR Weir



Graph 3: Head-Discharge Relationship for TR Weir



Graph 4: Head-Discharge Relationship for RTz Weir

For sharp-crested weirs whose heights are more than one-fifth of the total head (P/H0 > 0.2), the discharge coefficient is vary greater than 1. For weir heights less than about one-fifth the head, the contraction of the flow becomes increasingly suppressed and the crest coefficient decreases.

VI. CONCLUSION

1. From the test it has been observed that sharp-crested weir have maximum discharge for low head as compared to broad-crested weir.
2. The compound weir with combination of Rectangle-Rectangle (R-R) gives maximum discharge for low head.
3. Coefficient of discharge for sharp-crested weir is more than that of broad-crested weirs as in broad crested weir loss due to friction is observed.
4. When theoretical and experimentally results were compared it has been observed that the discharge for compound sharp-crested weirs is approximately 8-10% more than compound broad-crested weirs.
5. From the overall observation it can be concluded that for maximum discharge with low head is recommended to use compound weirs with the combination of Rectangle-Rectangle (R-R) weir.

VII. FUTURE SCOPE

There is a future scope to determine the coefficient of discharge by the field calibration method also to compare the laboratory results with the actual field discharge. Increase the scale of the weir prototype model at the time of field calibration because some geometrical parameters are change according to the field conditions. For field calibration some prerequisite are to be required for the weir testing at the time testing of weir on field for to avoid the losses due to the surrounding atmospheric conditions . Then perform the field calibration with proper suitable method and compare those discharges for same shapes of weirs with the same laboratory calculation.

VIII. ACKNOWLEDGEMENT

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REFERENCES

[1] A.S. Ramamurthy, R. Tadayon, and Z. Chen, J. Qu , "Numerical simulation of sharp-crested weir flows", NRC Research Press, October 2009, Volume 36, Page 1530-1534.
[2] A.Zahiri, X.Tang, H.Md. Azamathulla,"Mathematical modelling of flow discharge over compound sharp-crested weirs", Journal of Hydro-environment Research, August 2014, Volume 8, Issue 3, Page 194-199.
[3] Abdel Azim Mohamed Ali, Mohamed Ibrahim, A. I. Diwedar, "The Discharge Coefficient for a Compound Sharp Crested V-Notch Weir", Asian Journal of Engineering and Technology (ISSN: 2321 – 2462), October 2015, Volume 03 – Issue 05, Page 494-501.
[4] Ahmed M. El-Belasy, "Developing Formulae for combined weir and orifice (case study: EL-Fayoum weirs)", Alexandria Engineering Journal, August 2013, Volume 53, Issue 4, Page 763-768.
[5] Ali R. Vatankhah and S. Khalili, "Stage-Discharge Relationship for Weir–Orifice Structure Located at the End of Circular Open Channels", Journal of Irrigation and Drainage Engineering, August 2020, Volume 146, Issue 8, Page
[6] Ali R. Vatankhah, M. Khamisabadi, "Stage-discharge relationship for triangular and curved-edge triangular weirs", Flow Measurement and Instrumentation, October 2019, Volume 69, Page 130-139.

[7] Ali Shariq, Ajmal Hussain, Mujib Ahmad Ansari, “Discharge coefficient for side compound weirs in open channels”, Recent Innovations in Science, Technology and Engineering, December 2017, Page 179-188.
[8] Amir Hossein Azimi, N. Rajaratnam, “Discharge Characteristics of Weirs of Finite Crest Length”, Journal of Hydraulic Engineering, December 2009, Volume 135, Issue 12, Page 1081-1085.
[9] Anand V. Shivapur, M.ISH Raviraj H. Mulangi, H. S. Govardhan Swamy, “Use of Inclined Compound Triangular Notch-Weir To Improve Discharge Range”, The Indian Society for Hydraulics Journal of hydraulic Engineering, December 2009, Volume 15, Issue 3, Page 87-96.
[10] Ayşegül ÖZGENÇ AKSOY, Mustafa DOĞAN, “Experimental Investigation of the approach angle effects on the discharge efficiency for broad crested weir”, Anadolu University Journal of Science and Technology A- Applied Sciences and Engineering, May 2016, Volume 2016, Issue 2, Page 279-286.
[11] Carlos A. Gonzaleza, Hubert Chansonc, "Experimental measurements of velocity and pressure distributions on a large broad-crested weir", Flow Measurement and Instrumentation, June-August 2007, Volume 18, Issue 3-4, Page 107–113.
[12] Chyan-Deng Jan, Chia-Jung Chang, Feng-Hao Kuo,"Experiments on Discharge Equations of Compound Broad-Crested Weirs”, Journal of Irrigation and Drainage Engineering ASCE, August 2009, Volume 135, Issue 4, Page 511-515.
[13] Edson C. Bortoni, Mariana S. Rocha, Marcelo A. S. Rodrigues, Bianca C. S. Laurindo, “Calibration of weirs using unsteady flow”, Flow Measurement and Instrumentation, October 2017, Volume 57, Page 73-77.
[14] Ehsan Goodarzi, Javad Farhoudi, Naser Shokri, “Flow Characteristics Of Rectangular Broad-Crested Weir With Sloped Upstream Face”, Journal of Hydrology and Hydromechanics, February 2012, Volume 60, Issue 2, Page 87-100.
[15] Farzin Salmasi , Sanaz Poorescandar , Ali Hosseinzadeh Dalir, Davood Farsadi Zadeh ,"Discharge Relations for Rectangular Broad-Crested Weirs", Journal Of Agricultural Sciences, January 2012, Volume 17, Issue 4, Page 324-336.
[16] Hadi Arvanaghi, Ghorban Mahtabi, “Hydraulic Characteristics of Rectangular Combined Sharp-Crest Weir-Gate”, AENSI Journals Advances in Environmental Biology, October 2014, Volume 8, Page 32-38.
[17] Hamid Saadatnejadgharahassanlou, Rasoul Ilkhanipour Zeynali,Amin Gharehbaghi,Saeid Mehdizadeh,Babak Vaheddoost, "Three dimensional flow simulation over a sharp-crested V-Notch weir" , Flow Measurement and Instrumentation, March 2020, Volume 71, Page 90-97.
[18] Issam A. Al-Khatib, Mustafa Gogus, "Prediction models for discharge estimation in rectangular compound broad-crested weirs”, Flow Measurement and Instrumentation, April 2014, Volume 36, Page 1-8.
[19] J. Martínez, J. Reca, M. T. Morillas, J. G. López, "Design and Calibration of a Compound Sharp-Crested Weir”, Journal of Hydraulic Engineering ASCE, February 2005, Volume 131, Issue 2, Page 112-116.
[20] J. Martínez, J. Reca, M. T. Morillas, J. G. López, “Discussion of Design and Calibration of a Compound Sharp-Crested Weir”, Journal of Hydraulic Engineering ASCE, August 2006, Volume 131, Issue 2, Page 112-116.
[21] Jung-Tai Lee, Hsun-Chuan Chan, Chin-Kun Huang, Jan-Mou Leu, “Experiments on hydraulic relations for flow over a compound sharp-crested weir”, International Journal of Physical Sciences, March 2012, Volume 7, Issue 14, Page 2229-2237.
[22] K.H. Kulkarni, G. A. Hinge, “Compound Broad Crested Weir for Measurement of Discharge – A Novel Approach”, International Conference ISH – Hydro, December 2017.
[23] Ketaki H. Kulkarni, Ganesh A. Hinge, "Experimental study for measuring discharge through compound broad crested weir”, Flow Measurement and Instrumentation, October 2020, Volume 75, Page 253-259.
[24] Konstantinos X. Soulis, Nicholas Dercas, “Field Calibration of Weirs Using Partial Volumetric Flow Measurements”, Journal of Irrigation and Drainage Engineering, May 2012, Volume 138, Issue 5, Page 481-484.
[25] Meysam Nouri, Mohammad Hemmati, "Discharge coefficient in the combined weir-gate structure", Flow Measurement and Instrumentation, October 2020, Volume 75, Page 280-290.
[26] Mohamad Reza Madadi, Ali Hosseinzadeh Dalir, Davood Farsadizadeh, “Investigation of flow characteristics above trapezoidal broad-crested weirs”, Flow Measurement and Instrumentation, May 2014, Volume 38, Page 139-148.
[27] Mohammad Mahmoud Ibrahim, "Bed profile downstream compound sharp crested V-notch weir", Alexandria Engineering Journal, September 2015, Volume 54, Issue 3, Page 607-613.
[28] Rahul Pandey, Dr.S.K.Mittal, M.K. Choudhary "Flow Characteristics of Sharp Crested Rectangular Weir: A Review”, International Journal of Innovative Science, Engineering & Technology, March 2016, Volume 3, Issue 3, Page 171-178.
[29] Shaker A. Jalil, Safa S. Ibrahim, Rondk A. Jafer, “Surface Roughness Effects on Discharge Coefficient of Broad Crested Weir”, June 2014, Volume 7, Issue 24, Page 5227-5233.
[30] Vadoud Naderi, Mohammad Sadeghi Nasrabadi, Hadi Arvanaghi, "Effect of Height of Sharp-Crested Weir on Discharge Coefficient", International Journal of Sciences: Basic and Applied Research (IJSBAR), July 2014, Volume 3, Issue 6, Page 325-330.
[31] Wubbo Boiten, “V-Shaped Short-Crested Weir With Semicircular Cross Section”, Journal of Irrigation and Drainage Engineering, March 1984, Volume 110, Issue 4, Page 315-330.
[32] Hanifeh Imanian, Abdolmajid Mohammadian, Pouneh Hoshyar, "Experimental and numerical study of flow over a broad-crested weir under different hydraulic head ratios”, Flow Measurement and Instrumentation, August 2021, Volume 80, Page 102-114.
[33] Xin Zhang, Linjuan Yuan, Peng Yan Jiazhen Li, Xiangli He, “Rectangular sharp-crested weir calibration for low head and clinging flow regime”, Journal Irrigation Science, December 2014, Volume 33, Page 131-139.