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Flow Measurements in Rough Free Overfall

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ABSTRACT: In this paper, the relation between the brink and critical depth is studied experimentally and theoretically to predicted theoretical discharge equations using in rough free overfall. Three different; bed rough materials, sizes and distributions were used and tested experimentally to develop the discharge relationship. An equation is proposed to determine the flow rate using brink depth for a channel of known roughness, Froude number and normal depth. The equation shows that (95) % of the estimated discharge within (4) % error of the experimental data. The magnitude of the ratio (yb/yc) dependence of both the free overfall roughness materials and its distribution, the maximum values of this relation was happened at smooth free overfall and reduced gradually at rough one for wood material, then more decreases for 6mm and 2mm stone material.

Keywords: Free overfall, Brink depth, Normal depth, Bed roughness, Roughness distribution

1. Introduction

The free overfall flow is a departure from the hydrostatic pressure distribution causes by the pronounced accelerated down flow in the vicinity of the brink (S.Day, 2001).

A large number of studies have been carried out because of its importance, of possible usage of it as a discharge measuring device. Ferro V.(1992) presents an experimental study of a free overfall in a rectangular channel, having different values of channel width ,the relationship between end depth yb and critical depth yc had to be established as yb=0.76 yc , this relationship was used to obtain discharge equation. Rajaratnam et. al. (1976) and Davis et. al. (1998) investigated the effect of slopes and roughness on the brink depth. They found that the influence of roughness is negilable, but (yb/yc) was affected by the ratio of bed slope to critical slope (So/Sc).

Ahmad (2003) and Ahmad Z., and Azamathulla H.Md. (2012) presented a quasi-theoretical method to determine end depth ratio and end depth discharge relationship for both subcritical and supercritical flows in rectangular and trapezoidal channels, the brink pressure distribution coefficient was found, the end-depth relationship was 0.78 for a confined napped and 0.758 for unconfined napped. Ramamurthy et.al.(2004) studied free overfall to determine the vertical distribution of the velocity components and static presume heal at different points across the end section of a horizontal trapezoidal channel using momentum equation.

Ahmed et.al.,(2007) studied two models of free overfall, straight vertical and skewed end lip, and found the relationship between brink and critical depth, discharge equation for two models, and showed that the discharge for the skewed lip model was greater 13% than straight vertical. Ahmed Y.M. (2008) presented an experimental study and analysis for effect of channel slope on straight vertical and skew free overfall for a rectangular channel with different slopes, and find the discharge over skewed model is greater by (21%) from straight vertical. Ahmed Y.M. (2009) studied the behavior of free surface flow on a rectangular free overfall which has a triangular shape, the results prevail, that the ratio of brink depth to critical depth at center line for falls inclined with flow direction was greater by (3%) than that falls in the opposite direction, this value increased to (27%) when Froud number increased. Tigrek et.al., (2008) presented experimental study and found the effects of the bed roughness and slope of the channel on the brink depth. Seyed et. al. (2011) studied the relationship between the brink depth (yb) and the normal depth (yn), known as end-depth-ratio (EDR=yb/yn) in flat based Circular and U-Shaped Channels. Ehsan et. al. (2017) studies free over fall in inverted semicircular channel theoretically to compute (EDR) and (SDD) relationships and compared it with experimental data. Raad I.and Safa H. (2018) presented experimentally work to examine characteristics of flow for free overfalls in triangular channels, they found that (EDR=0.755)

In the present study, the effect of the bed roughness material sizes and its distribution are investigated. Experimental data and theoretical calculation lead to develop a relation to the observed flow rate at the end depth structure.

2. Experimental Setup

Experiments were conducted in the hydraulic laboratory of the Water Resources Department, University of Mosul, Iraq. At a rectangular flume of 0.3m in width, 0.45m in depth and 10m long shown in Figure (1).

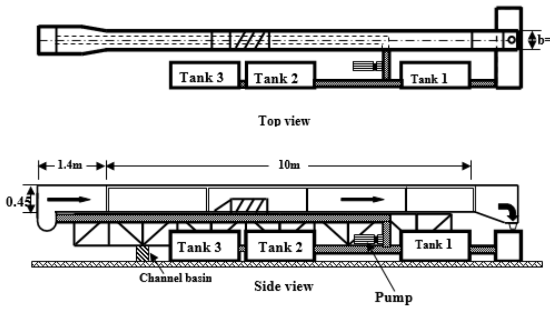

Figure 1. Channel sketch

The discharge was conducted using a rectangular sharp crested weir installed upstream of the channel, with dimensions (30×30×1) cm. The upstream water head (Hw) of approximately 4, 5.5, 6.5, 7.5 and 9.5 cm were produced in a flume. The free overfall was made from wood (where the free overfall was a special case of broad crested weir) of 0.3m in width, 0.15m in height and 1m long. Roughness were made using stone in 6mm and 2mm dimensions and a piece of cylindrical wood 1cm in diameter, spacing and height, were located in three different cases: two rows; 20cm distance between them, three rows; 10cm distance between them, for all roughness types and three rows zigzag 10cm distance between them for wood and full bed roughness of area (20×30) cm2 for stone 6mm and 2mm, shown in Figures (2 and 3).

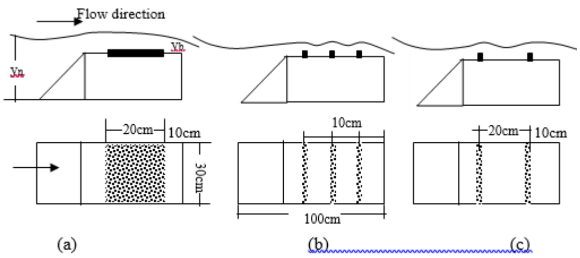

Figure 2. Models of (2mm and 6mm) stone roughness distribution; (a) Full, (b) three rows, (c) two rows

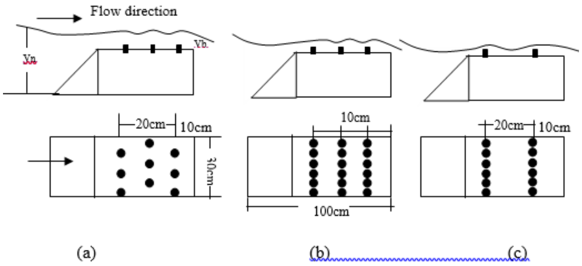

Figure 3. Models of (10mm) wood Roughness distribution; Zigzag, (b) three rows, (c) two rows

The water surface profiles (W.S.P.) were measured using a point gage over and between roughness rows, head over brink yb, normal depth yn and head over a sharp crested weir upstream Hw was measured, so actual discharge Qact can be calculated from the following equation:

Qact=0.714Hw1.5 (1)

Where Qact in (L/s) and Hw in (cm)

This equation was found from volumetric calibration by measuring Hw and volume of water with respect to time, the data shown in Table (1), while some of experimental data collected and computed where shown in Table (2).

Table 1. volumetric discharge calculations

Hw(cm)	Volume(l)	Time(s)	Q(l/s)
2.5	20.2	7	2.886
3	20.2	5.5	3.673
4.5	20.2	3	6.733
5.5	20.2	2.2	9.182
6.5	20.2	1.7	11.882
7.5	20.2	1.4	14.429
8.5	20.2	1.2	16.833
9	20.2	1.1	18.364

Table 2. some of experimental and calculated data

HW (cm)	Q_{act} (l/s)	q (l/s)	y_b (cm)	y_c (cm)	y_n (cm)	y_n/y_b	F	y_b/y_c	K (cm)	Q_{the} (l/s)	cd	eq.4 y_b/y_c	eq.8 Q_{th}
9.5	20.90	69.68	5.2	7.910	9.6	1.846	3.792	0.657	0	26.35	0.793	0.668	20.39
7.5	14.66	48.88	4	6.245	7.9	1.975	4.803	0.640	0	19.67	0.745	0.649	14.36
6.5	11.83	39.44	3.5	5.412	7.1	2.028	5.542	0.646	0	16.75	0.705	0.655	11.60
5.5	9.209	30.69	3.2	4.579	6.1	1.906	6.550	0.698	0	13.34	0.690	0.704	9.089
4	5.712	19.04	2	3.330	4.8	2.4	9.006	0.600	0	9.316	0.613	0.618	5.460
9.5	20.90	69.68	5.1	7.910	10.5	2.058	3.792	0.644	1	30.14	0.693	0.655	20.40
7.5	14.66	48.88	4	6.245	8.5	2.125	4.803	0.640	1	21.95	0.668	0.648	14.38
6.5	11.83	39.44	3.5	5.412	7.8	2.228	5.542	0.646	1	19.29	0.613	0.654	11.63
5.5	9.209	30.69	2.9	4.579	7.4	2.551	6.550	0.633	1	17.83	0.516	0.641	9.040
4	5.712	19.04	2	3.330	6	3	9.006	0.600	1	13.01	0.438	0.615	5.503
9.5	20.90	69.68	4.8	7.910	9.8	2.041	3.792	0.606	0.6	27.17	0.769	0.618	20.33
7.5	14.66	48.88	3.8	6.245	8.1	2.131	4.803	0.608	0.6	20.42	0.718	0.617	14.34
6.5	11.83	39.44	3.2	5.412	6.7	2.093	5.542	0.591	0.6	15.36	0.770	0.601	11.53
5.5	9.209	30.69	2.75	4.579	6.3	2.290	6.550	0.600	0.6	14.00	0.657	0.611	8.966
4	5.712	19.04	2	3.330	5	2.5	9.006	0.600	0.6	9.904	0.576	0.618	5.460
9.5	20.90	69.68	4.8	7.910	9.1	1.895	3.792	0.606	0.2	24.31	0.859	0.619	20.26
7.5	14.66	48.88	3.7	6.245	7.6	2.054	4.803	0.592	0.2	18.56	0.790	0.601	14.31
6.5	11.83	39.44	3.2	5.412	7.1	2.218	5.542	0.591	0.2	16.75	0.705	0.599	11.57
5.5	9.209	30.69	2.7	4.579	6.1	2.259	6.550	0.589	0.2	13.34	0.690	0.600	8.960
4	5.712	19.04	1.9	3.330	5.1	2.684	9.006	0.570	0.2	10.20	0.559	0.587	5.471

3. Experimental Program

Experiments, were conducted in smooth and rough free overfall, the roughness materials (k) were made from 10mm wood, 6mm and 2mm stone in three different types, full, 3rows and 2rows for stone rough and zigzag, 3rows and 2rows for wood rough, so normal depth before the structure, brink depth, water surface profile and discharge were measured. The total number of experiments conducted was 65. There were 5 experiments run for the smooth surface of the structure and 60 experiments run for rough surface, Figure (4).

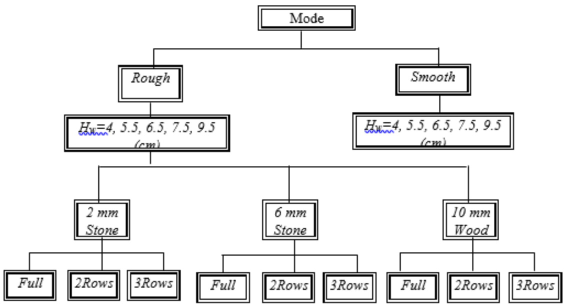

Figure 4. Experimental program for present work

4. Dimensional Analysis

For a rectangular free overfall the following variables are involved in affecting the behavior of the brink depth:

yb=brink depth(L); yn=uniform flow depth(L); yc=critical depth(L); q= discharge unit (L3L-1T-1) g=gravitational acceleration (LT-2); ρ=density of water (ML-3); b=channel width (L); μ=dynamic viscosity (ML-1T-1) and the variables (k1,k2,k3)= end depth roughness (L) thus the dimensional discharge equation parameter can be written as:

$$yb=f(yn,yc,q,g,\rho,b,\mu,k1,k2,k3) \quad (2)$$

Using dimensional analysis, the functional relationship can be obtained:

$$yb/yc=C1+C2(yn/yb)^{C3}+C4(k/yb)^{C5}+C6F^{C7}+C8(b/yb)^{C9} \quad (3)$$

Where, F = Froude number at uniform flow depth

C1-C9=coefficients

The following equation was obtained using statistical package for the social sciences (SPSS, V.17) by satisfying experimental data collected for all cases of roughness materials and distribution with all flow rates, the coefficients of eq. (3) were found and then this equation can be written as

$$yb/yc=25.849+0.194(yn/yb)^{-0.106}+0.001(k/yb)^{0.186}+9.022F^{0.061}+17.658(b/yb)^{-0.037} \quad (4)$$

With correlation coefficient ($R2$) =0.97.

Figure (5), shows the relation between brink and critical depth measured in all cases of roughness material and distribution, as well as the data computed using eq. (4). As depicted in this Figure, the magnitude of the ratio (yb/yc) seems to be independent of both the free overfall roughness materials and its distribution.

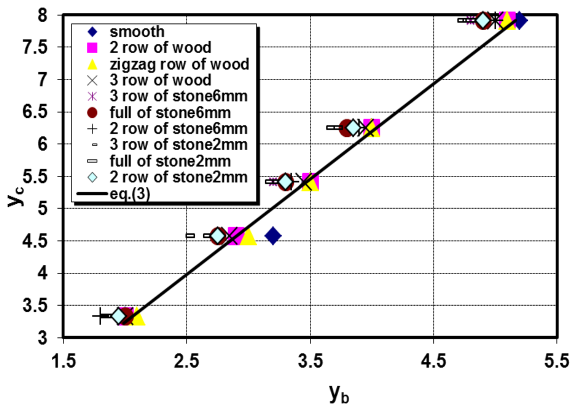

Figure 5. The relation between brink and critical depths measured for all cases and computed using eq. (3).

This Figure shows that the maximum values of relation (yb/yc) were happened at smooth free overfall, reach to (0.698), so these values decreases gradually at rough one when roughness distribution at (2 rows, 3rows zigzag and 3rows) respectively, for wood material, then these values more decreases when roughness distribution at (2 rows, full and 3rows) respectively for 6mm and 2mm stone material, reach to (0.600), so the maximum roughness effected at 10mm, 6mm and 2mm height respectively.

Two rows roughness distribution has maximum effects because of greater flow turbulence in the region between the rows, which will cause effecting in end depth ratio (EDR) at the end of free overfall.

5. Discharge Prediction

One of the most important corollaries of the agreement as established of the data reported of various origins is the possibility of obtaining a discharge relationship [10]

The critical depth can be calculated using

$$y_c = \sqrt[3]{\frac{q^2}{g}} \tag{5}$$

eq. (5) can be written as

$$q = \sqrt{g}\, y_c^{\,3/2} \tag{6}$$

When brink depth measured yc can be written depend on brink depth as $y_c = \left(\dfrac{y_b}{y_b / y_c} \right)$, so eq. (6) became

$$q = \sqrt{g} \left(\frac{y_b}{y_b / y_c} \right)^{3/2} \tag{7}$$

When, Q = q*b, so eq. (7) can be written as

$$Q_{th} = \sqrt{g} \left(\frac{y_b}{y_b / y_c} \right)^{3/2} * b \tag{8}$$

The comparison of observed discharge and that calculated using eq.(8) for all cases, as well as the discharge calculated by Rajaratnam et. al. [3] and Ferro V. [2], the figure shows the agreement of data calculated by present work can be shown in Figure (6).

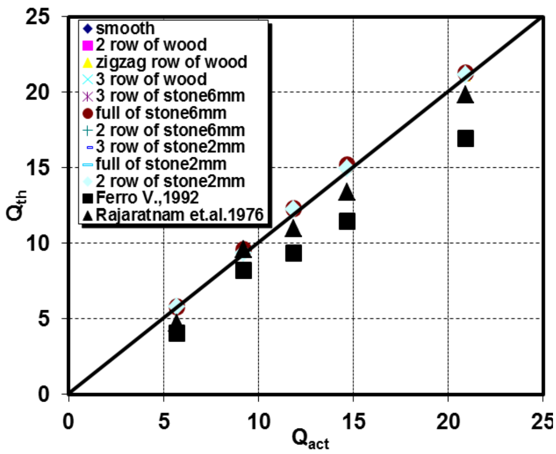

Figure 6. The comparison between observed and calculated discharge

According to eq. (4), Figure (7) Shows the comparison of discharge as predicted by eq. (8) and that observed experimentally with respect to (yb/yc) for all cases of bed rough material and its distribution.

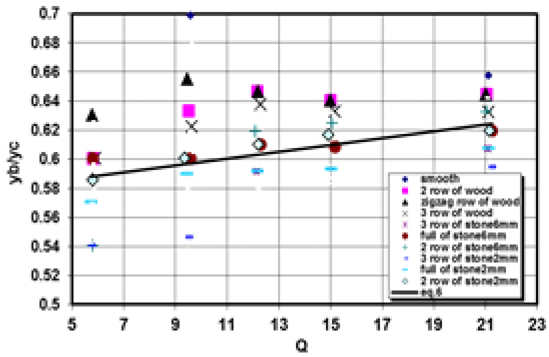

Figure 7. The relation between discharge and brink to critical depth

The figure shows agreement of relation that computed and observed experimentally.

The percentage (P) % of the resulting estimated discharge values with an error not greater than ±(x) % of the experimental discharge is given in Figure (8). It can be seen that (75)% of estimated values using eq.(7) are within error ±(3) % of the experimental discharge, and (95)% are within error ±(4).

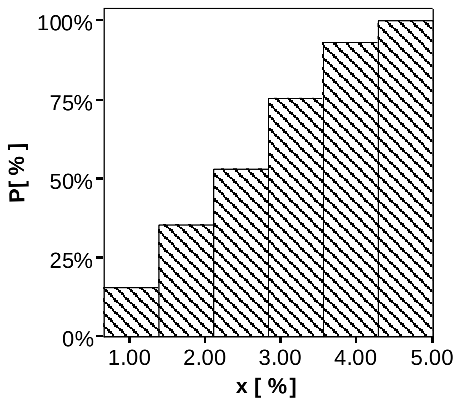

Figure 8. Percentage (P) of estimated discharge with an error not greater than ±(x) %

6. Conclusion

A computational of discharge equation for free overfall in horizontal channel with various roughness dimensions and distribution has been presented.

The magnitude of the ratio (yb/yc) independent of both the free overfall roughness materials and its distribution, the maximum values of relation (yb/yc) were happened at smooth free overfall.

These values decreases gradually at rough one when roughness distribution at (2 rows, 3rows zigzag and 3rows) respectively for wood material, then these values more reduces when roughness distribution at (2 rows, full and 3rows) respectively for 6mm and 2mm stone material.

eq.(8) can be used when known brink and normal depth of free overfall, this equation shows that (75)% of the estimated discharge within (3)% of the experimental one and (95) % within (4)% error.

Nomenclatures

Symbol	Description
B	Channel width (L)
F	Froud number
G	Gravitational acceleration (LT-2)
Hw	Head over sharp crested weir (L)
k1, k2, k3	Roughness height (L)
Q	Unit Discharge (L3L-1T-1)
Qact	Actual discharge (L3T-1)
Qthe	Theoretical discharge (L3T-1)
yb	Brink depth (L)
yc	Critical depth (L)
yn	Normal depth (L)
M	Dynamic viscosity (ML-1T-1)
P	Density of water (ML-3)

7. References

[1] Ahmed Y. M., Moayed S. K., Mwafaq Y. M., (2007). " Variation of Water Depth on Normal and Skewed Broad Crested Weirs", Tikret Univ. Jou. Of Eng., Vol. 14, No. 1.

[2] Ahmed Y.Mohammed (2008). "Effecting of Channel Slope on Flow Characteristics for Straight Vertical and Skew Free overfal", Alrafidain Eng. Journal, 17(1), 80-90.

[3] Ahmed Y.Mohammed (2009). "Hydraulic Characteristics of Free Overfall with Triangular End Lip", 33rd IAHR Congress: Water Eng. For a Sust. Env., 1188-1199.

[4] Ahmad Z., (2003), " Quasi-Theoretical End Depth Discharges Relationship for Rectangular Channels." Journal of Irrigigation and Drainage Engineering, ASCE, 129(2),138-141.

[5] Ahmad Z., and Azamathulla H.Md. (2012), " Quasi-theoretical end-depth–discharge relationship for trapezoidal channels." Journal of Hydrology, 456–457 (2012) 151–155.

[6] Davis A.C.,Brain G.S. and Jacob R.P.,(1998), " Flow Measurement in Sloping Channels with Rectangular Free Overfall ." Journal of Hydraulic Engineering, ASCE, 124(7), 760-763.

[7] Dey S., (2001), "Flow Measurement by End-Depth Method in Inverted Semicircular Channels."Flow Measurement and Instrumentation, 12(4), 253-258.

[8] Ehsan A., Mustafa E., and Mohammad K. (2017), " Direct Prediction of Discharge at Supercritical Flow Regime Based on Brink Depth for Inverted Semicircular Channels." Journal of Irrigation and Drainage Engineering, ASCE, 143(9): 06017010-1-4.

[9] Ferro V., (1992), " Flow Measurement with Rectangular Free overfall ", Journal of Irrigation and Drainage Engineering, ASCE, 118(6),650-657.

[10] Rajaratnam N., Durfakula M. and Spyridon B. (1976). " Roughness effects on rectangular free overfall", Jou. Of Hyd. Div., ASCE, 102(5), 599-614.

[11] Ramamurthy A.S., Zhai C. and Junying Q, (2004), " End Depth Discharges Relation at Free Overfall of Trapezoidal Channels", Journal of Irrigation and Drainage Engineering, ASCE, 130(5),432-436.

[12] Ramamurthy A.S., Zhai C. and Junying Q, (2004), " End Depth Discharges Relation at Free Overfall of Trapezoidal Channels", Journal of Irrigation and Drainage Engineering, ASCE, 130(5),432-436.

[13] Raad I.and Safa H. (2018),"Characteristics of flow over the free overfall of triangular channel." MATEC Web of Conferences 162, 03006. https://doi.org/10.1051/matecconf/201816203006

[14] Seyed V.N., Mohammed K.B., Mohammed R.C. and Mark S., (2011), "Flow Overfalls in flat based Circular and U-Shaped Channels." Flow Measurement and Instrumentation, 22(1), 17-24.