Gravel Roughness and Channel Slope Effects on Rectangular Free Overfall

Dr. Mwafaq Y. Mohammed[1] Ahmed Y. Al-taee[2] and Azza N. Al-Talib[3]

Abstract

The experiments where made in hydraulic laboratory, water resources Dept., Mosul University, Iraq. In this paper the effect of bed roughness for free overfall on flow characteristics in open channel are studied.

The characteristics include, water depth over free overfall, critical and brink depth at lip of free overfall.

The aim of the study is to know the effect of bed roughness of free overfall on flow depths (normal, critical and brink depth) we obtained a relation between these depths and compared the those with results without roughness for the same discharges.

Six empirical formulas were found for describing the relationship between the critical and brink depths, and their relation to slope, channel bed roughness as well as to the of roughness distribution. The study shows that the full bed roughness at steeper slopes has greater effect.

Keywords: Overfall, brink depth, bed roughness

1 Dept. of Water Resources Engineering, Coll. of Eng., Mosul Univ., Mosul, Iraq.
2 Dept. of Water Resources Engineering, Coll. of Eng., Mosul Univ., Mosul, Iraq.
3 Dept. of Water Resources Engineering, Coll. of Eng., Mosul Univ., Mosul, Iraq.

1.Introduction:

A rectangular free overfall refers to the downstream portion of a rectangular channel. The depth of flow measured at end section before the water draw down is known brink depth (he).Many studies on over falls deals with measuring (he) and the relation with critical depth (hc) so, the ratio (he/hc) important on these studies. Rajartnam et.al.,(1976) conducted a study for a greater range of roughness and found that for a relative roughness (K/hc) less than 0.1, the curve produced by Delleure et.al.,(1956) was accurate in predicting (he/hc),at values of (K/hc) greater than 0.1, (he/hc) was smaller than that predicted, because of the influence of roughness. The presented method requires only a knowledge of slope and (he) to determine (he/hc) and discharge (q).

Gupta et.al.,(1993) presented analysis solution for experimental data collected and fined calibration curve for the prediction of discharge. Ferro, (1999) simulated the free overfall by the flow over a sharp crested weir, and he found a relationship between the end depth and the discharge for both subcritical and supercritical flow in rectangular and trapezoidal channels, for each cross section shape, discharges predicted using the theoretical relationship are compared with the available experimental data, and obtained the values of he/hc=0.715.Davis et. al.,(1999) presented the results of a study to model the upper surface profile of free rectangular overfall. It was found that an empirically adjusted free overfall parabola equation adequately describes this profile. Dey, (2002) studied two separate methods to analyze the free overfall in circular channels with flat base. First applying a momentum approach based on the Boussinesq assumption, this need to determine pressure coefficient experimentally, and the end-depth relationship has been related to the critical depth. Secondly, a simplified approach to computation of end-depth for a free overfall from critical channels with flat base has been presented by simulates the flow over a sharp crested weir. Ahmed,(2003) studied a quasi-theoretical method to determine end depth ratio and end depth discharge relationship for both subcritical and supercritical flows in rectangular channels, the brink pressure distribution coefficient was found, the end-depth relationship was 0.78 for a confined nappe and 0.758 for unconfined nappe .Ahmed,(2005) presented the simulation of the free overfall in an inverted semi-circular channel with a sharp-crested weir, for the determination of discharge from a single measurement of end depth. The end-depth ratio is almost constant with average value 0.713.

In this paper, two size of gravel roughness with different types of bed rough distribution kinds were studied in a rectangular channel with different bed slope, and found the relationship between brink depth and critical depth.

2.Dimensional analysis:

The flow over sloping rough free overfall in a rectangular channel by a series of experiments were scheduled and run. The following variables are involved in affecting the behavior of the flow at a free overfall.

he=brink depth (L);Q=discharge (L^3T^{-1});ho=normal depth (L);So=channel bed slope; g=gravitational acceleration (LT^{-2}); ρ=density of water (ML^{-3}); hc=critical depth (L); K=roughness height (L),thus the dimensional brink depth equation parameters can be written as following:

he=f(Q, ho, So, g, ρ, hc, K)… …………..(1)

using dimensional analysis ,the functional relationship can be obtained:

$$\frac{h_e}{h_c} = f\left(\frac{h_o}{h_c}, \frac{K}{h_c}, F_{r,} S_o\right) \quad \ldots\ldots\ldots\ldots(2)$$

Where Fr=Froud number

3.Experimental Work:

The experiments were conducted in a metal rectangular flume with glass sides,300mm in width and 10m in length shown in fig.(1).The flume was set to slopes of 0, 0.005(1/200), 0.01(1/100) respectively, the discharge were conducted by made a rectangular sharp crested weir 300mm in width and 300mm in height installed upstream channel, the upstream steady-state normal depths of approximately 4,5.5,6.5,7.5 and 9.5cm were produced in flume. The free overfall was made from wood 300mm in width, 150mm height and 1m length. Roughness was made by using two different gravel gradients size 2mm and 6mm, each one was allocated in three different cases: Two rows 1 cm width for each row, 20 cm distance between them. Three rows 1cm width for each row, 10cm distance between them, and full roughness bed allocated at area 20X30cm^2,show fig.(2).

A point gauge mounted on rails along the channel allowed measuring the water surface profile (W.S.P.) at free overfall, (over and between roughness rows), head over brink he normal depth over free overfall ho and head over sharp crested weir upstream Hw were measured, figs.(1&2), so actual discharge Qact can be calculated from the following equation which is calibrated in the volumetric way by measuring Hw and volume of water with respect to time:

$Q_{act}=0.714\,H_w^{1.5}$……………...….(3)

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

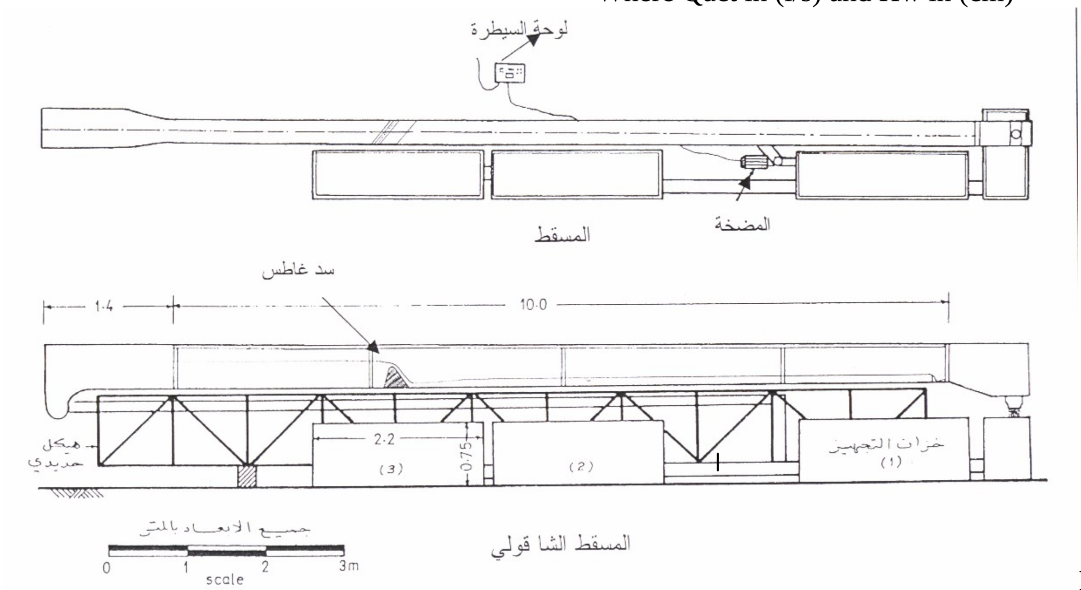
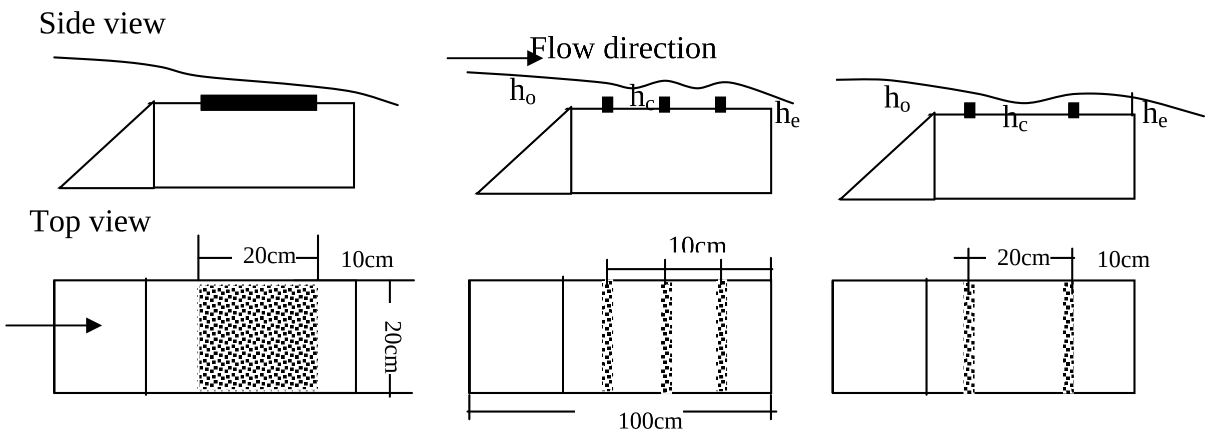


Fig. (1) The laboratory channel



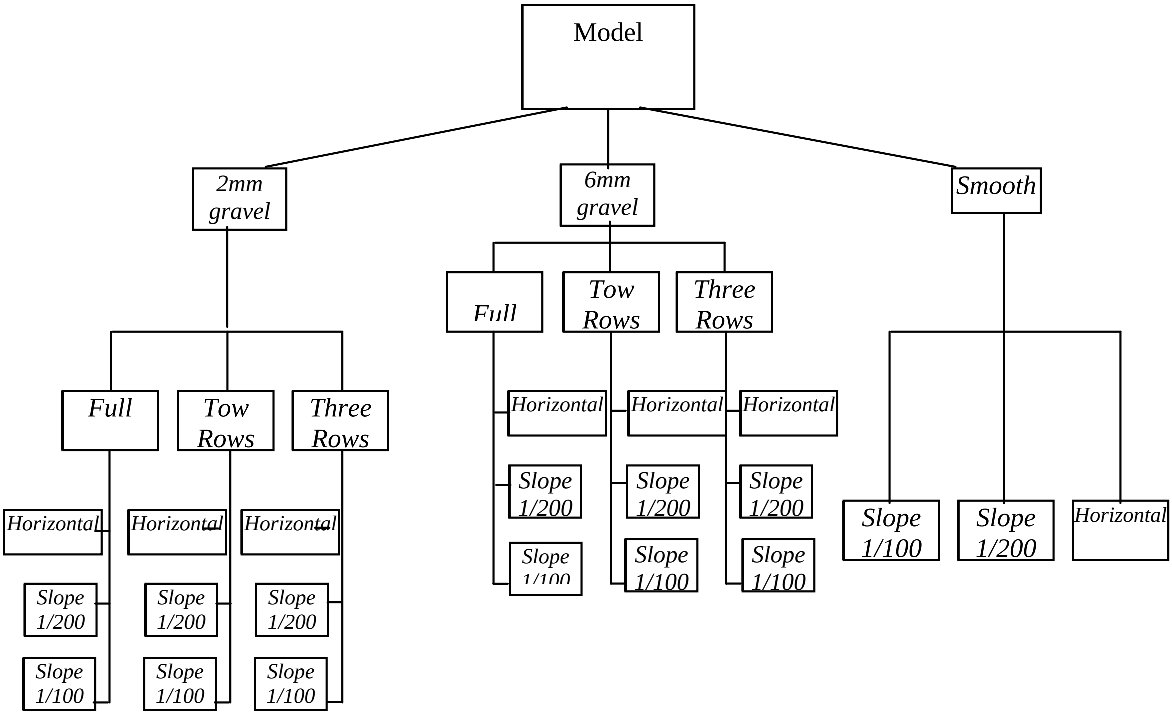
(a) **Full bed roughness on area (20*30) cm^2**

(b) **Three rows bed roughness at distance 10 cm between them**

(c) **tow rows bed roughness at distance 20 cm between them**

Fig. (2): Models of Roughness distribution

4.Experimental Program:



5.Results:

One hundred and five flows were found to satisfy the required criteria, 15 flows on the smooth bed with three different slopes (horizontal,1/200 and 1/100).90 flows for the gravel rough bed,45 of these flows for 2mm gravel rough bed with the three different slopes and the three types of roughness distribution. In the same manner for 6mm gravel rough bed conducted.

Water surface profile (W.S.P), normal depth, brink depth and discharge were measured in each experiment. The relationships between brink depth he and critical depth hc , the relation of he/hc with Froud number Fr ,coefficient of discharge Cd and ratio of roughness height to critical depth K/hc were plotted and studied for all cases ,(the three different slopes, the two types of bed roughness as well as smooth and the three cases of bed roughness distribution).

6.The relation between he and hc:

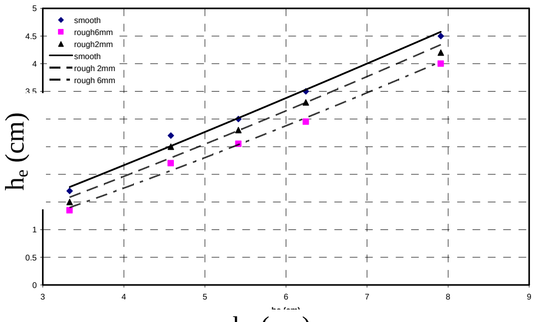
The relationship between brink depth he and critical depth hc were depicted in figures (3,4 and 5).

As depicted in these figures , the magnitudes of he increase when discharge values increase.

Fig.(3) represents different types of roughness ,three rows of roughness distribution and bed slope 1/100.It can be seen that the values of he for smooth bed are greater (6%) than 2mm bed roughness and (17%) than 6mm bed roughness, because of roughness effects (Tigrek et.al.,2008).

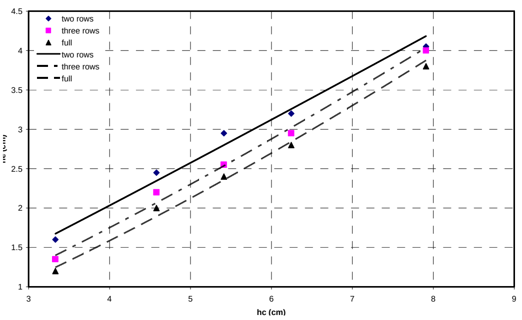
Fig.(4) shows a method of roughness distribution for 6mm gravel rough and 1/100 bed slope. As depicted in this figure, the magnitude of he for two rows gravel roughness are (11%) greater than three rows gravel roughness and (16%) greater than full bed roughness (20 x 30cm2) gravel roughness, because of increasing roughness effects , (Rajartnam et.al.,1976).

Fig.(5) represents bed slope effect on 2mm gravel roughness with two rows of roughness distribution. In this figure it was shown that for (hc=6 cm) for horizontal bed slope the magnitudes of he are greater (14%) than 1/200 bed slope and (28%) greater than 1/100 bed slope , because of increasing roughness effects when bed slope increases (Davis et.al.,1998).



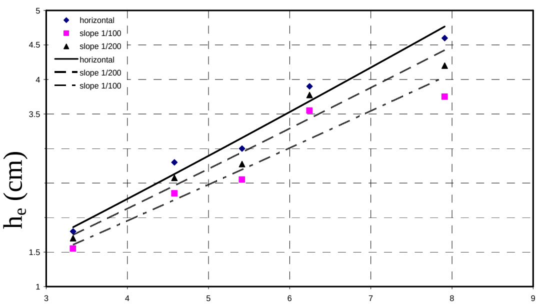
h_c (cm)

Fig.(3): Different types of roughness with three rows of roughness distribution and bed slope 1/100



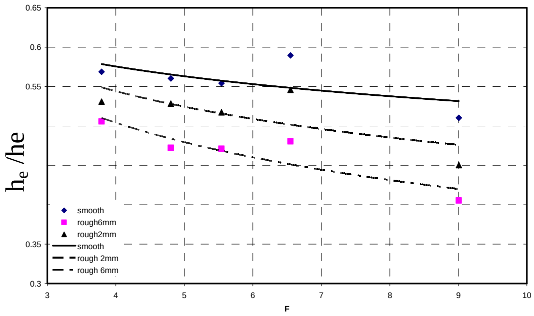
h_c (cm)

Fig.(4): Methods of roughness distribution for 6 mm gravel rough and 1/100 bed slope



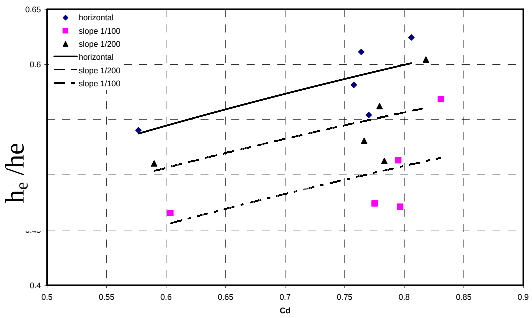
h_c (cm)

Fig.(5): Bed slope effect on 2 mm gravel roughness with two rows of roughness distribution



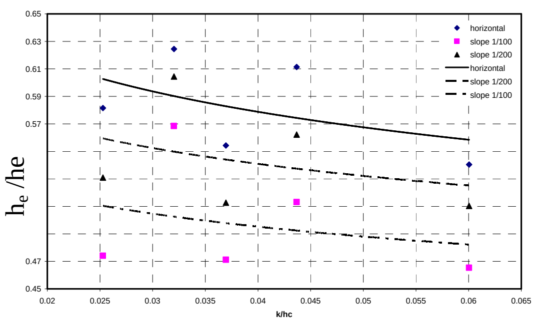
Fr

Fig.(6): The relation between he/ hc and Fr for three rows roughness distribution (2mm,6mm roughness as well as smooth bed) and 1/100 bed slope



C_d

Fig.(7): The relation between he/ hc and coefficient of discharge Cd for two rows roughness distribution and 2mm bed gravel roughness



k/h_c

Fig.(8): The relation between he/ hc and K/hc shown for two rows roughness distribution and the three types of bed slope

7.Predicting he/hc :

One of the most important corollaries of the agreement as established of the data reported of various origins is the possibility of obtaining relationship of he/hc using K/hc and So.

Equation (2) can be used to determine values of he/hc and can be rewritten as:

$$\frac{h_e}{h_c} = c_1 + c_2 (\frac{K}{h_c} S_o)^{0.5} \quad \text{..................(4)}$$

This equation can be used to determine he/hc for all types of gravel roughness, distributions and channel bed slopes using statistic program (spss,v10). So, for full bed roughness 20x30 cm2 of 6mm gravel, he/hc can be fined from the following equation:

$$\frac{h_e}{h_c} = 0.57 - 3.53(\frac{K}{h_c} S_o)^{0.5} \quad \text{..........(5)}$$

And correlation coefficient =0.867

For two rows 6mm gravel roughness , he/hc can be fined from the following equation:

$$\frac{h_e}{h_c} = 0.57 - 1.9(\frac{K}{h_c} S_o)^{0.5} \quad \text{..............(6)}$$

And correlation coefficient =0.7

For three rows 6mm gravel roughness he/hc can be fined from the following equation:

$$\frac{h_e}{h_c} = 0.56 - 2.5(\frac{K}{h_c} S_o)^{0.5} \quad \text{...........(7)}$$

And correlation coefficient =0.9

For full bed roughness 20x30 cm2 of 2mm gravel roughness , he/hc can be fined from the following equation with correlation coefficient =0.82

$$\frac{h_e}{h_c} = 0.59 - 4.13(\frac{K}{h_c} S_o)^{0.5} \quad \text{...........(8)}$$

For two rows 2mm gravel roughness, he/hc can be fined from the following equation with correlation coefficient =0.71

$$\frac{h_e}{h_c} = 0.58 - 4.(\frac{K}{h_c} S_o)^{0.5} \quad \text{.................(9)}$$

For three rows 2mm gravel roughness , he/hc can be fined from the following equation with correlation coefficient=0.775

$$\frac{h_e}{h_c} = 0.62 - 5.12(\frac{K}{h_c} S_o)^{0.5} \quad \text{.........(10)}$$

The manning coefficient (n) is one of the major variables whose effect on the brink depth and its value was obtained by comparing experimental values of discharge and measured values of ho and So in conjunction with manning equation.

The results of he/hc for present study from equations (5-10) for all cases reported by Davis et.al.(1998) and Tigrek et.al.(2008), were depicted in figures (9 and 10) for 2mm and 6mm gravel roughness respectively, enhances the utility and the validity of this study.

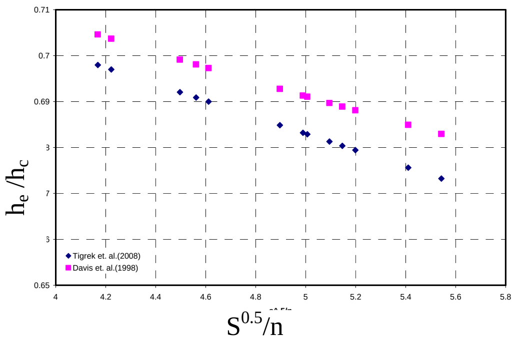


Fig.(9): The relation between he/hc and S0.5/n for present study reported by Davis et.al.(1998) and Tigrek et.al.(2008) for 2 mm bed gravel roughness

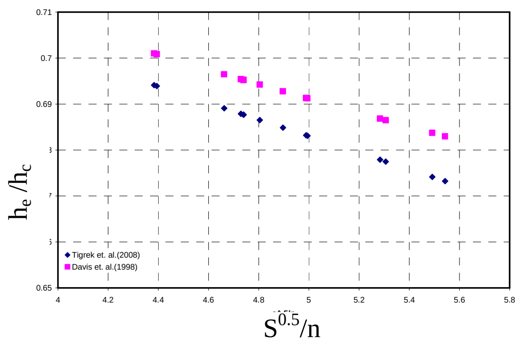


Fig.(10): The relation between he/hc and S0.5/n for present study reported by Davis et.al.(1998) and Tigrek et.al.(2008) for 6 mm bed gravel roughness

8.Conclusions:

This study shows the results of effect slope ,roughness, as well as method of roughness distribution on free rectangular overfall. It was found that the ratio of he/hc for full bed rough 20x30 cm2 of 6 mm gravel has more effect at steeper slopes. Six relationships were obtained to predict he/hc .All these relationships were compared with Davis et.al. (1998) and Tigrek et.al.(2008) to ensure their utility and validity.

The relationships between he and hc, ratio of he/hc and Fr, Cd, K/hc are plotted and studied for all these cases.

9.References:

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

Ahmed Z. (2005), "Flow Measurement Using Free Overfall in inverted Semi-Circular Channel. " Flow Measurement and Instrumentation, 16(10), 21-26.

Davis A.C., Jacob R.P.and Brain G.S., (1999), " Estimating Trajectory of Free Overfall Nappe. ", Journal of Hydraulic Engineering, ASCE, 125(1), 79-82.

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.

Dey S., (2002), "Free Overall in Circular Channels with Flat Basic a Method of Open Channel Flow Measurement." Flow Measurement and Instrumentation, 13(1), 209-221.

Ferro V., (1999), " Theoretical End Depth Discharges Relationship for Free Overfall ", Journal of Irrigation and Drainage Engineering, ASCE, 125(1),40-44.

Gupta R. D., Jamil M. and Mohsin M., (1993), " Discharge Prediction in Smooth Trapezoidal Free Overfall (positive, zero and negative slope)." Journal of Irrigation and Drainage Engineering, ASCE, 119(2),215-224.

Rajartnam N., Muralidhar D. and Beltaoss S. (1976), " Roughness Effects on Rectangular Free Overfall". Journal of Hydraulic Engineering Div.,102 (5),599-614.

Tigrek S., Firat C.E. and Ger A.M, (2008) ," Use of Brink Depth in Discharge Measurement" Journal of Irrigation and Drainage Engineerge, ASCE, 134(1),89-95.

Received 28/9/2009