

Analysis of Hydraulic Characteristics of Cutthroat Flume

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Abstract

The aim of this research is to calculate experimentally the coefficient of discharge for cutthroat flume. Nine models were constructed with different angles ($\alpha=30^\circ, 45^\circ, 60^\circ$), for each angle, Three ratios of width of cutthroat to width of channel B_c/B were used ($B_c/B=20, 33.3, 50$); the slopes of the channel were changed five times ($S=0.0, 0.001, 0.002, 0.003, 0.004$) for each ratio. The results show that the coefficient of discharge C_d increases as the slope S increases, and as the ratio B_c/B , is the ratio of head of water through cutthroat to width of cutthroat h_c/B_c , critical depth through cutthroat to width of cutthroat y_c/B_c increases, and for a constant ratio B_c/B , C_d increases as α increase. An empirical model was predicted to calculate the C_d in terms of the perimeters ($S, h_c/B_c, y_c/B_c, B_c/B$, and α), finally the water surface profiles were drawn and there were in a continuous trend.

Keyword: discharge coefficient, cutthroat flume

تحليل الخصائص الهيدروليكية للقناة العنقية

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الخلاصة

يهدف البحث الى دراسة معامل التصريف لقناة عنقية، حيث تم إنشاء واستخدام تسعة نماذج بزوايا مختلفة ($\alpha=30^\circ, 45^\circ, 60^\circ$) ولكل زاوية استخدمت ثلاث نسب لعرض العنق إلى عرض القناة ($B_c/B = 20, 33.3, 50$) ولكل نسبة تم تغيير ميل القناة خمسة مرات ($S=0, 0.001, 0.002, 0.003, 0.004$). أشارت نتائج الدراسة بأن معامل التصريف C_d يزداد بزيادة ميل قاع القناة S ويزداد بزيادة النسب $B_c/B, h_c/B_c, y_c/B_c$ وعند ثبوت B_c/B فإن C_d تزداد بزيادة الزاوية α كما تم استنباط علاقة وضعية لحساب معامل التصريف C_d بدلالة المتغيرات ($S, y_c/B_c, h_c/B_c, B_c/B, \alpha$) وتم رسم مخطط لسطح الماء وتبين بانه سلسا ومستمر. الكلمات الدالة: معامل التصريف، القناة العنقية

Introduction:

Measurement of a curate discharge is a well-known and an interesting hydraulic problem. It is useful for application objectives such as forecasting of flood discharged of a fixed return period, hydraulic design of river engineering structures and measurement of sediment transport and soil erosion (Ferro 2002a). Flumes having a local dimension of channel width are widely used as discharge measurement structures. In practice discharge measurement must not always be recorded permanently, but evaluated at various locations of a channel system (Hager 1985).

A low-cost device would be appreciated having a moderate accuracy with respect to discharged (say= $\pm 5\%$). The modification to be described consists of a cylinder made of stainless steel, or high density, plastic-type material with high precision regarding its geometry. It is positioned into a channel of well-defined cross-section. Discharge then be computed using critical flow theory provided cylinder and channel geometry are known and upstream flow depth has been observed (Hager 1985). Measurement channels having flat bottom and (De Marchi et. al. 1977, Sine in Giorgio Baiamonte et. al. 2007) and parshall flumes are characterized by a particular shape of the cross-section area with various degrees of convergence and subsequent divergences. The shape aims to contract the width of the original channel in order to assure, for a free outflow condition that the critical depth occurs in the narrow section. According to (Di Stefano and Ferro 2002, sine in Giorgio Baiamonte et. al. 2007), the stage discharge relationship of a generic Endress+Hauser Venturimeter, characterized by a narrow section of width B_C (m), can be expressed with the following equation:

$$Q = 1.8513 * B_C^{0.9736} * h^{1.5264} \dots \dots \dots (1)$$

In which:

Q= discharge measured in $m^3 s^{-1}$: and h=water depth measure in m.

Recently, a new device for measuring discharge in open channel flow was proposed by (Samani and Magallanez 2000). The measurement principle is based on establishing a channel contraction (Hager 1986, Samani and Magallanez 1993) using a cylinder which is, as (Hager 1985) asserted. The simplest body having a streamlined shape using semi cylinders applied to the walls of laboratory channel having a zero slope with width B the rectangular cross-section is narrowed to the throat width B_C . The diameter of the cylinders have been established for determining the chosen values of the contraction ratio $r=B_C/B$ ($0.407 \leq r \leq 0.6$). Ferro, (2007) depended on both the geometry of the flume and the slope of the channel in which the flume is placed. The results of laboratory investigation are reported, the runs are carried out in a laboratory channel with contraction ratio ranging from (0.17 to 0.81) and using in addition to the already verified zero slope flume, seven values of slopes in the range of (0.5-3.5%). Manekar, V. at el., (2007) established a single relation between discharge and upstream head in dimensionless form, applicable to cutthroat flumes of different sizes ,the experiment were carried on seven flumes of different ratios of length of cutthroat flume to throat width of cutthroat flume (L/W). Samani's research (2000) research included two steps(1) laboratory testing and equation development and (2) Field testing of the flume ,The flume was rectangular and constructed from plywood of 3m long , with 28cm , two cylinders of polyvinyl chloride (PVC) were attached to each of the side walls at the downstream side . Dimensionless calibration curves were developed for three different contractions of (40%, 54% and 60%) .Afield scale flume were constructed and used to measure various discharged

rates. The measured flow rates were compared with the predicted flow rates based on the flume can be constructed at considerably less cost. The maximum submergence ratio was measured at 80%. In this research the characteristics of flow through a cutthroat are studied, the proposed cutthroat was constructed by contracting the flow with placement of a triangular shape column attached to the side walls of rectangular channel as shown in(Fig.1).

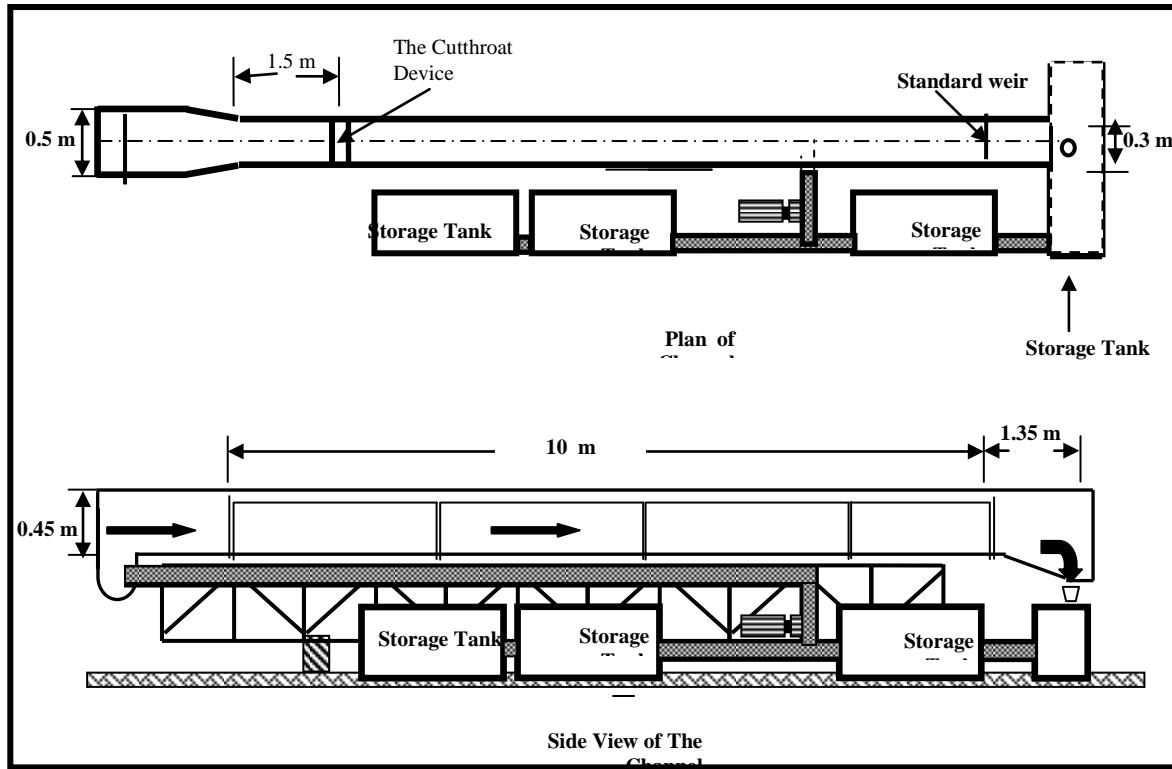


Figure (1) Channel Cross Section

Experimental Set-Up and Experiment

Experiments were carried out in the Hydraulic Laboratory of the Water Resources Department, University of Mosul, Iraq.

The experiments were carried out in a channel of working length 10 m, with a cross section of 0.3m width and 0.45 m high. The walls of the channel were of toughened glass with number of plexiglass panels incorporated, and the bed of the channel consisted of stainless-steel plates. A pair of adjustable instrument rails were fitted on the top of the channel. Two

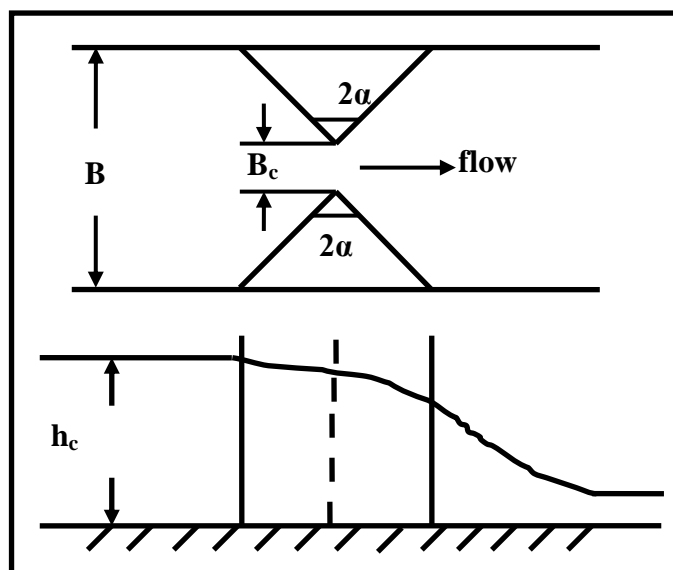


Figure (2) Details of the Tested Model

movable carriages equipped with point gauges were mounted on the rails as shown in Fig.(1). Three groups of cutthroat models were manufactured from wooden sheet 4 mm thickness, each group has a triangular shape column with ($\alpha=30^\circ, 45^\circ, 60^\circ$). For each angle the width of cutthroat (B_c) changed three times ($B_c = 6, 10, 15\text{cm}$) for each B_c the slope of the channel is changed five times ($S=0.0, 0.001, 0.002, 0.003, 0.004$), the details of the tested models were shown in Fig.(2).

Tested model were fixed at a distance of 1.5 m downstream of the channel inlet, and the discharged were measured with standard full width thin plate sharp crested rectangular weir with dimensions(15*30*1)cm located at the outlet of the channel ,the standard weir were manufactured according to the British Standard(British Standard Institute, 1965). The centerline of the water surface profiles were recorded for each test, and the discharge passing through the cutthroat was measured with a standard weir. The water surface level and the head above the standard weir were measured with precision point gauge, whose least count was 0.4 mm. In all tests the free falling napes at the downstream end of both the cutthroat and the standard weir were fully ventilated, more than 225 experiments were carried out through the work, the experimental program is shown in Fig(3)

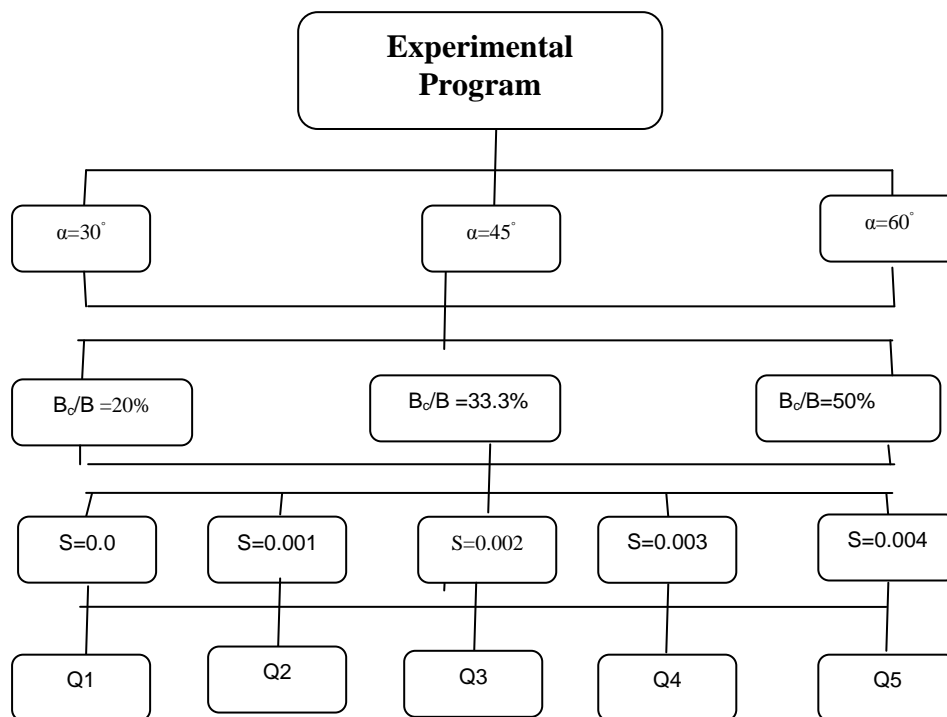


Fig. (3) The Experimental Layout

Dimensional analysis

The relationship between the depth of water upstream the cutthroat h and the discharged passing through the cutthroat of width B_c inside a channel of width B and slope S is shown as follows(Ferro 2002a):

$$Cd = f(hc, B, Bc, \alpha, S) \dots\dots\dots (2)$$

Where

C_d = coefficient of discharge.

h_c = depth of water upstream the cutthroat.

B = width of the channel.

B_c = width of the cutthroat.

α = the triangular angle of the column create the cutthroat.

S = the slope of the channel under study.

Dimensional analysis was carried out using Buckingham's pi- theorem, equation (3) may be formed as follows :

$$Cd = \left(hc/B_c, B_c/B, \alpha, S \right) \dots \dots \dots (3)$$

Discussion and Analysis of Results:

Using theory and laboratory experiment the coefficient of discharged C_d for the cutthroat is calculated as follows:

$$Cd = Q_{act}/Q_{the} \dots \dots \dots (4)$$

Where:

Q_{act} = Actual discharge passing through the standard weir. (العمرى 2009):

$$Q_{act} = 0.58 * h^{1.5} \dots \dots \dots (5)$$

h =head over standard weir.

$$Q_{the} = B_c * \left(g * \left(\frac{2h_c}{3} \right)^3 \right)^{0.5} \dots \dots \dots (6)$$

Where:

Q_{the} , Theoretical discharge passing through cutthroat.

The dimensional analysis shows that the coefficient of discharge (C_d) depends on the ratios (h_c/B_c), (y_c/B_c), the slope of the channel bed (S), and the ratio (B_c/B). The relation between coefficient of discharge (C_d) and the dimensional parameters (y_c/B_c), (h_c/B_c) were drawn for different ratios of (B_c/B) =20%, 33.3% and 50%) and different channel slopes (S =0.0, 0.001, 0.002, 0.003, and 0.004) and different angles (α =30°, 45°, and 60°) as discussed below:

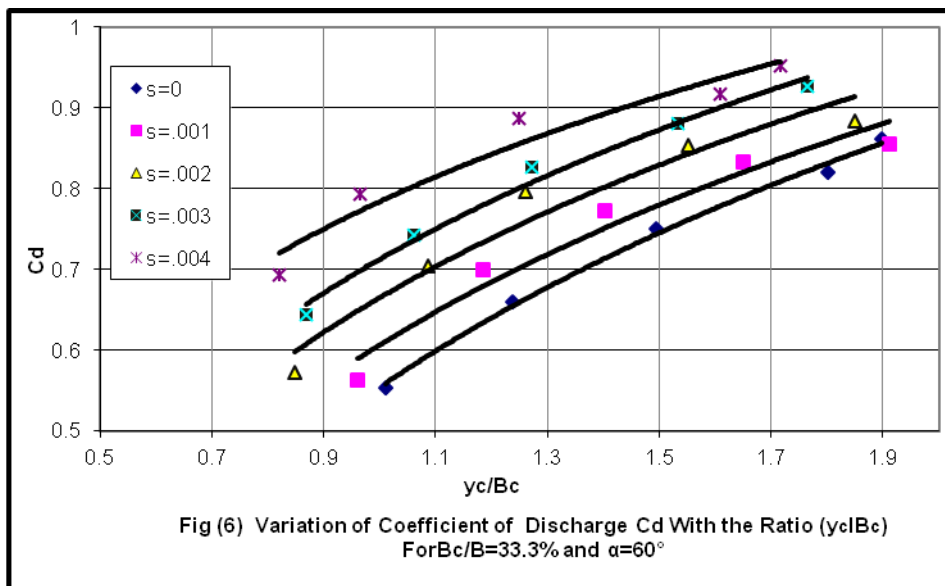
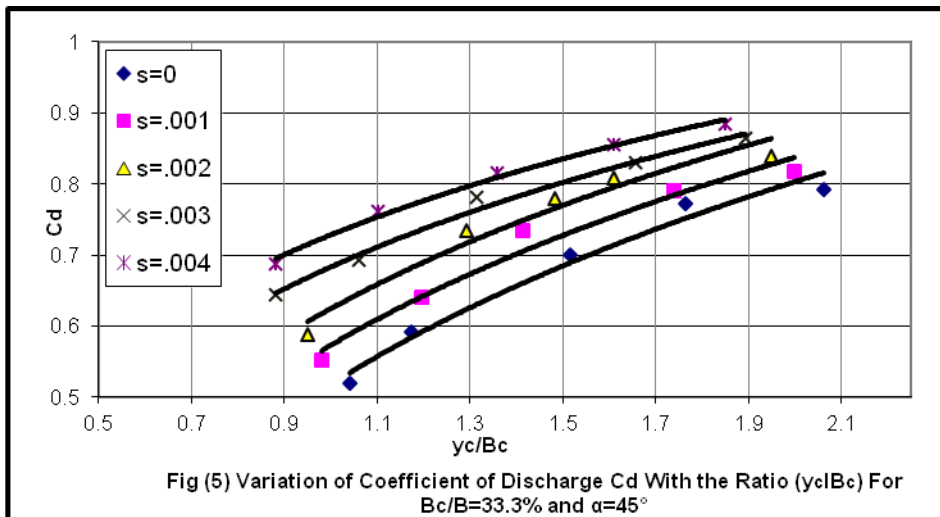
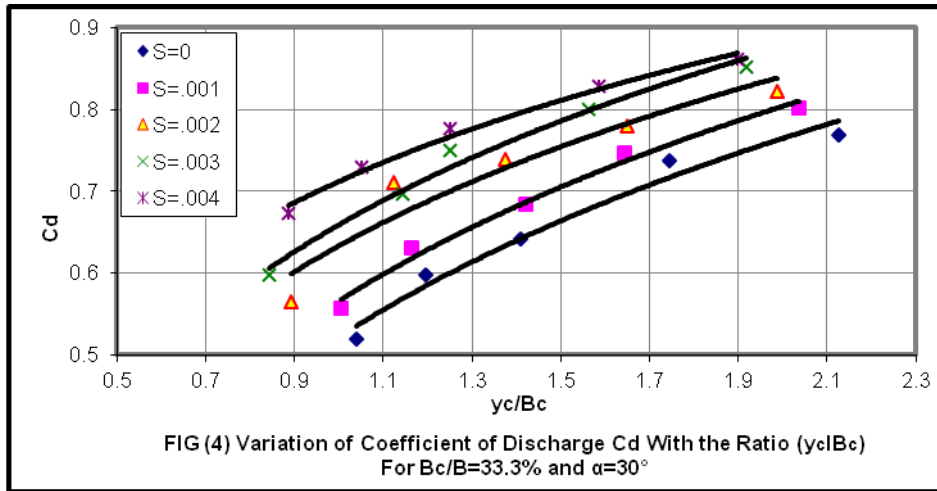
1-Variation of (C_d) with (y_c/B_c)

The relation between the coefficient of discharge C_d and the ratio of (y_c/B_c) is drawn in Figs.(4, 5, and 6) for different ratios, different angles and different slopes.

Fig.(4) shows the relation between (C_d) and (y_c/B_c) for (α =30°, B_c/B =33.3%), Fig.(5)for(α =45, B_c/B =33.3%), and Fig(6) for (α =60°, B_c/B =33.3%), these figures show the following:

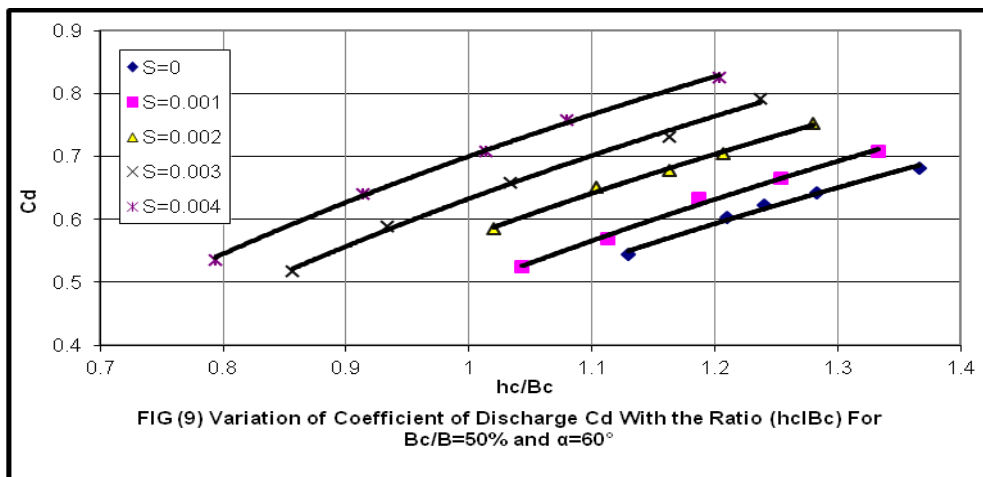
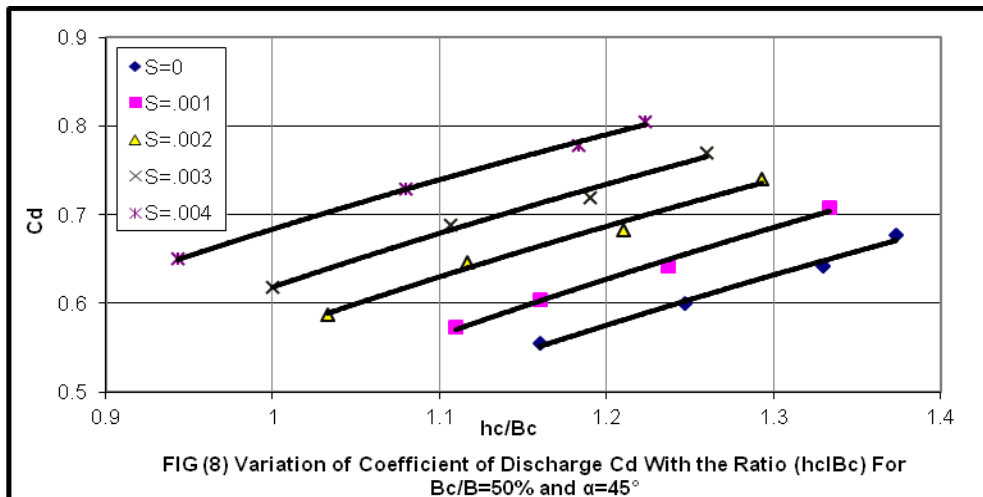
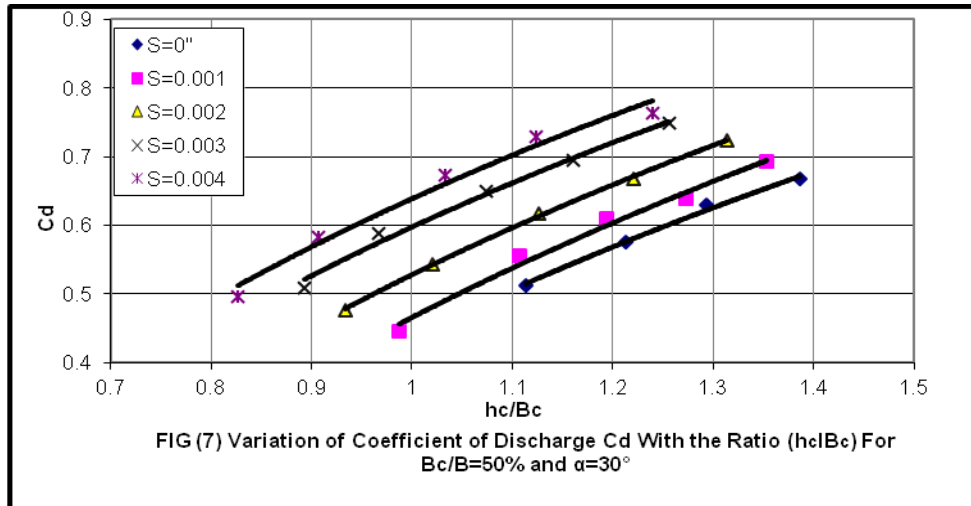
- a- As the ratio y_c/B_c increases C_d increases.
- b- C_d increases as the channel slope increases.

c- When B_c/B constant for each slope C_d increases as α increases .



2- Variation of C_d with the ratio h_c/B_c

The relation between C_d and the ratio h_c/B_c was drawn in Figs(7, 8 and 9) for different angles ($\alpha=30^\circ, 45^\circ,$ and 60°) and different channel slopes ($S=0.0, 0.001, 0.002, 0.003,$ and 0.004) for $B_c/B = 50\%$ respectively



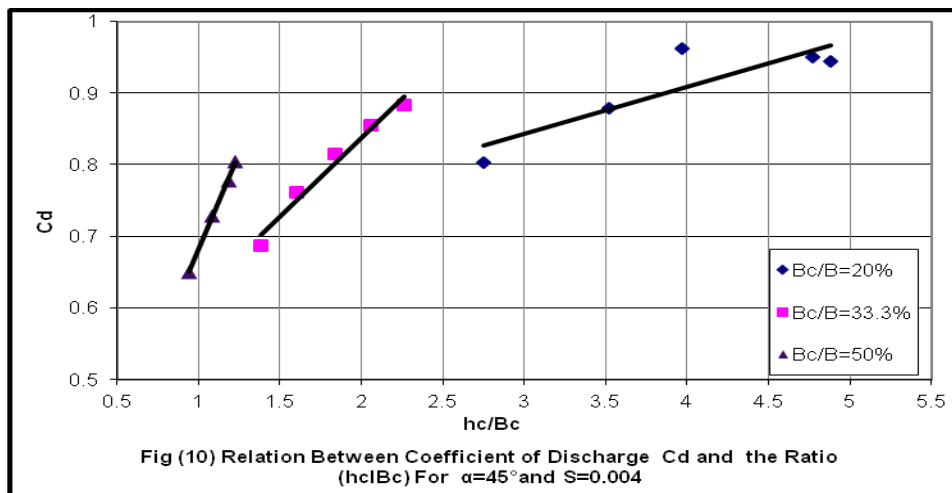
From these Figs it is shown that :

a- C_d increases as the ratio h_c/B_c increases .

b- C_d increases as the channel slope increases .

c- For each slope and for a constant ratio of(B_c/B) C_d increases as α increases.

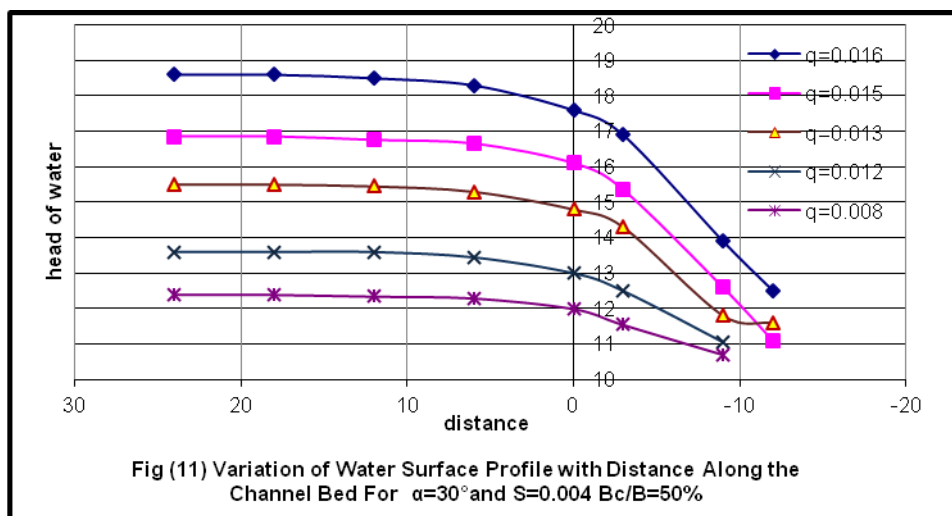
Fig.(10) shows the variation of C_d with the ratio (h_c/B_c) for different ($B_c/B = 20\%$, 33.3% and 50%) for $\alpha=45^\circ$, $S=0.004$,

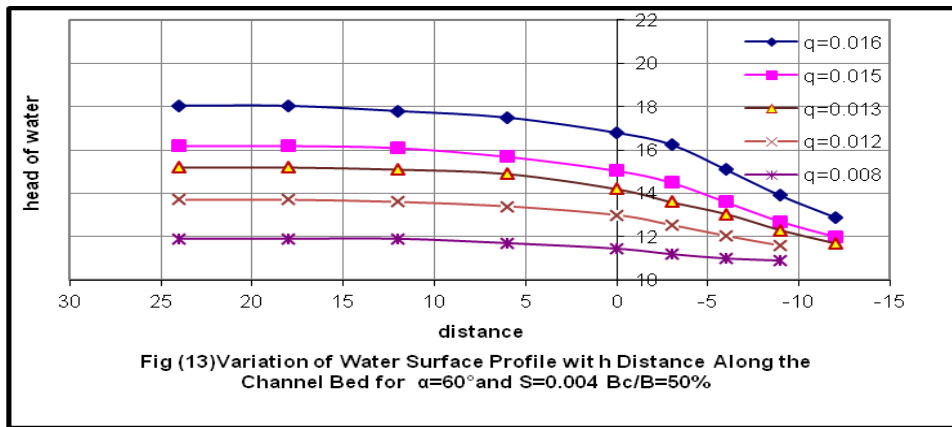
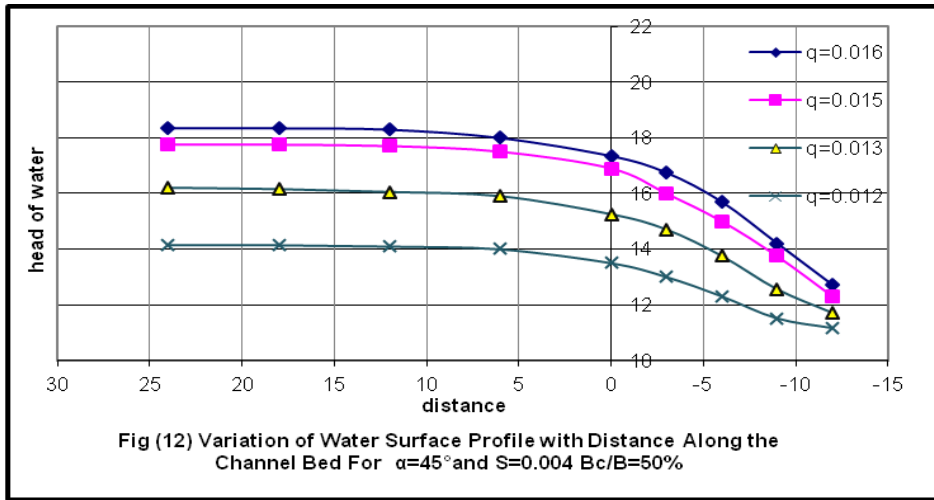


and this fig. shows for a constant α and a constant slope of the channel bed, C_d increase as the ratio B_c/B decrease and the results are constant and correct for all α and all slopes.

3- Water surface profiles:

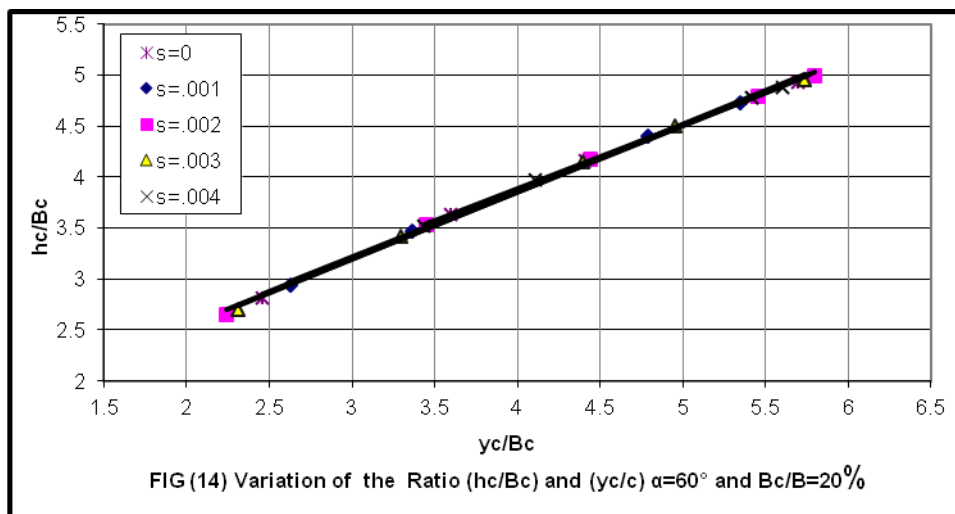
The experimental results of the measurement of water- surface profiles along the center line of the cutthroat show a smooth and continuous descending trend from the point of measurement to the entrance section toward the out let of the cutthroat. Figs (11, 12, 13) show a sample of water surface profile for ($\alpha = 30^\circ$, 45° , and 60°) for ($B_c/B = 50\%$) and ($S=0.004$) respectively.





4- Variation of h_c/B_c with y_c/B_c :

Fig 14 shows the relation between h_c/B_c and y_c/B_c for $\alpha=45^\circ$ and $B_c/B = 20\%$.



It is shown from this Fig. that the slope of the channel bed has no effect this is correct for ($\alpha = 30^\circ$, and 60°) and for ($B_c/B = 33.3\%$ and 50%).

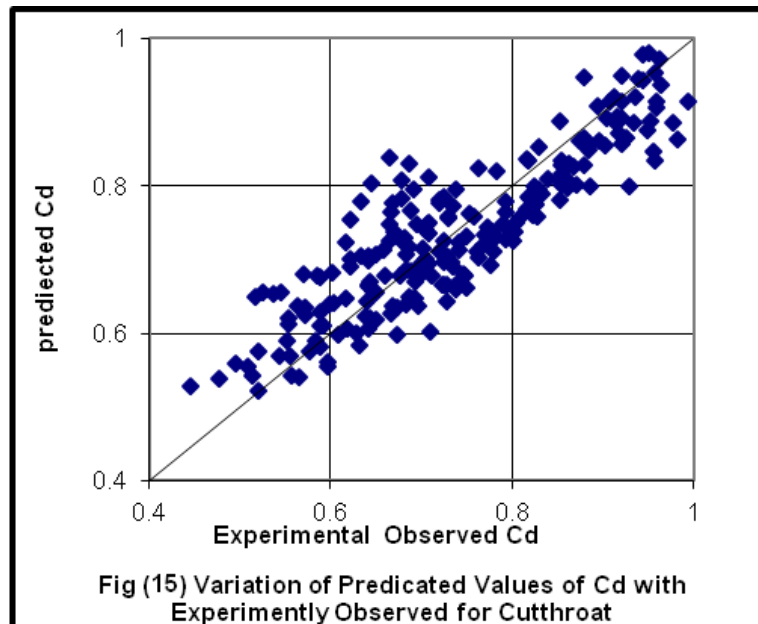
5-Predicted Model

All experimental results of all cutthroat angles(α) all channel slopes(S) and all ratios (B_c/B) were used as input data in (SPSS program V.11) to obtain a linear empirical relationship for variation of C_d with the parameters(h_c/B_c , S, y_c/B_c , B_c/B , and α) in following form:

$$Cd = -0.5 + h_c/B_c + 29.8S - 0.4y_c/B_c + 0.9B_c/B + 0.2\alpha \dots \dots (7)$$

With correlation coefficient $R^2=0.75$.

The relation between C_d values predicted by equation (7) and those observed experimentally are plotted in Fig. (15) which indicate a good agreement between the calculated and predicted values of C_d .



Conclusions:

From the experimental results of this study ,the following conclusions can be drawn:

1. For all channel slopes and all cutthroat angles and all ratios B_c/B :
 - a. For a constant ratio(B_c/B), (h_c/B_c) and(y_c/B_c), C_d increases as α increases.
 - b. Coefficient of discharge (C_d) increases as y_c/B_c , h_c/B_c and, when the channel slope increases .
2. Water surface profiles along the centerline of the cutthroat show a smooth and continues descending trend from the point of measurement to the entrance section toward the outlet of the cutthroat
3. A general expression was obtained for estimation of (C_d) with respect of (B_c/B), (h_c/B_c), (y_c/B_c), slope of the channel bed (S), and the angle of the cutthroat (α).

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List of notation:

Q= Discharge measured in $L^3 T^{-1}$.

h= Depth of water measured in L.

h_c = Depth of water upstream cutthroat in L.

B= Width of channel in L.

B_c = Width of the cutthroat in L.

g= Acceleration due to gravity $L T^{-2}$

C_d = Coefficient of discharge.

S= Slope of the channel under study.

A= Triangular angle of the column create the cutthroat.

Q_{act} = Actual discharge passing through the standard weir $L^3 T^{-1}$.

Q_{the} = Theoretical discharge passing through the cutthroat $L^3 T^{-1}$.

y_c = Critical depth through the cutthroat = $(q^2 / gb^2)^{1/3}$.

The work was carried out at the college of Engineering. University of Mosul