Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

Vol. 10, No. 2, pp. 48-59, June 2017

MODELING OF ONE DIMENSIONAL FLOW OVER SEMICIRCLE CRESTED WEIR PROFILE USING (HEC-RAS) PROGRAM

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(Received: 5/4/2016; Accepted: 29/6/2016)

ABSTRACT: - A semicircle crest profile extending across full width of laboratory channel (suppressed) provides measurements of discharge – head under free flow condition. According to these measurements an empirical head – discharge relationship has been established. Dimensional analysis is carried out to establish independent parameter (R/H) which represents relative crest curvature and dependent parameter $\left(\frac{q}{g^{1/2}H^{3/2}}\right)$. Regression analysis and solver function in Microsoft excel is used to determine the flow equation, to obtain a relationship between depending discharge and the independent parameters affecting the flow. Non-linear equation for estimating the discharge coefficient of the weir model was developed. The accuracy of HEC-RAS software is examined for describing water surface profiles, computation of rating curve and the occurrence of the critical depth .The HEC-RAS program results are compared with the laboratory measurements. Yield affair agreement between them. The weir coefficient of semicircle crest profile is greater than that for the basic broad crested weir and the flow upstream of the weir is subcritical .Transitional flow occurs on the weir crest and the flow along downstream weir face is supercritical within the range of modular discharges.

Keywords: HEC-RAS, semicircle crest, dimensional analysis, rating curve, discharge coefficient, flow equation.

1-INTRODUCTION:

The most crest weir profiles are used, ranging from sharp crest, to round tops of wall, and ogee profile crest [(1)]. In this study a semicircle crested weir of (4cm) radius was experimentally studied. The basic feature of the present model is the strong curvature of the flow, resulting in conversion of static to kinetic energy and the pressure distribution isn't hydrostatic[(2)] .theoretical models have been developed to obtain characteristics of flow passing circular crested weirs. The most common models are (1) irrotational flow (2) shallow curvilinear flow (3) free vortex model [(3)]. In the present study, Dimensional analysis based on Buckingham,s theorem was used to give expression of flow equation. The one dimensional steady flow model of HEC-RAS was used to develop water surface profile, and to produce the rating curve flow, Since the flow over weir crest is two-dimensional, but some of the physical constraints seen in a two - dimensional model can be overcome. The flow can be simulated in one (dimension) by using a series of cross-sections [(4)]. This assumption made in this hydraulic modeling. The ability of HEC- RAS model is examined for describing free surface flow over semicircle crested weir, and establishing the head discharge relationship which is one of the main objectives of this study.

2-THEORITICAL ANALYSIS:

2.1 HEC-RAS (RIVER ANALYSIS SYSTEM):

HEC-RAS is one of the most widespread models used to calculate water-surface profiles and energy grade line in 1-D, steady flow analysis. The fundamental hydraulic equations that govern 1-D, steady flow analysis includes continuity equation, energy equation, and flow resistance equation [5]. For HEC-RAS project, a set of data files associated with a particular river Systems are categorized into three required components, the geometric data, flow data, and plan data. The geometry data consist of description of the size, shape, and connectivity of stream cross sections. The flow data contains discharge rates. Finally, plan data contain information pertinent to the run specification of the model including a description of the flow regime. The dimensionless Froude number (Fr) is used to characterize flow regime.

2.1.1 STANDARD STEP METHOD:

Based on the concept of energy conservation, the standard step method uses the fundamental of hydraulic equations to iteratively calculate water-surface profiles and energy grade lines. Energy can be converted from one form to another but the total energy within the domain remains fixed. For the purpose of the standard step method, the energy equation is written as[6]:

$$Y_1 + Z_1 + \alpha_1 \frac{V_1^2}{2g} = Y_2 + Z_2 + \alpha_2 \frac{V_2^2}{2g} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Figure (1) illustrate back water computation between adjacent cross sections using the energy equation where (Q) is the discharge, EGL is energy grade line, and XS is cross section.

2.1.2 ORGANIZATION STRUCTURE OF HEC-RAS PROGRAM:

In one dimensional hydraulic modeling, it is assumed that all water flows is varied in longitudinal direction only [6] .One dimensional models represents the terrain as a sequence of cross sections and simulate flow to estimate the average velocity and water depth at each cross section. This model (HEC-RAS) is selected because it represents the most basic changing of flow path. A change in topography would affect the model. Work with the HEC-RAS program was started by creating a project. Two types of data (geometric data and steady flow data) were needed to be entered into the project.

2.1.3 GEOMETRIC DATA:

The schematic of the channel to be modelled was drawn. Data of the cross sections along the channel were entered. These data include the station and elevation coordinates, reach length, channel width at the sections, Manning's coefficient, and contraction, expansion coefficient are considered in the present study. (30) Cross sections were created for flow pattern to perform the simulation process with the desired accuracy. Manning's coefficient was set within the allowable range (0.009-0.013) [7] for the channel used in the laboratory work.

2.1.4 STEADY FLOW DATA:

This data include the number of flow profiles to be computed for the weir for a given flow rates, and the boundary conditions. The laboratory data of the (flow rates, measured flow depths, and the tail water depths) were used as boundary conditions in the simulations. Once the necessary data were entered, the program became ready to run a steady flow simulation. There were three options for the computation of the flow surface profile in the program: subcritical, supercritical, and mixed flow regime. The flow profile over the semicircle crested weir is characterized by a flow change from subcritical to supercritical due to the geometry of the weir. Therefore, the mixed flow regime was adopted. After the computations were finished, the generated water surface profiles could be viewed in different tabular and graphical forms within the HEC-RAS program.

2.2 DIMENSIONAL ANALYSIS:

The selected parameters that have an influence on the flow rate (q) over this type of weir per unit width can be functionally expressed as follows:

$$f(q, H, R, g, L, \rho, \mu, \sigma) = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where:

q = discharge over the weir per unit width, $m^3/s/m$
H = upstream water head above the weir crest,
R = Radius of the circular crested weir
g = acceleration due to gravity
L = crest Length of weir (which is equal to πR)
ρ= mass density of the fluid
μ= dynamic viscosity
σ= surface tension
By using (Buckingham π theorem), the parameters in equation (2) may be expressed in nondimensional form as:

$$\frac{q}{g^{1/2}H^{3/2}} = f_1 \left(\frac{\mu}{H^{3/2}\ \rho g^{1/2}}, \frac{\sigma}{\rho g\, H^2}, \frac{R}{H}, \frac{L}{H} \right) \dots\dots\dots\dots\dots\dots\dots (3)$$

Where $\left(\frac{q}{g^{1/2}H^{3/2}}\right)$ is discharge in the dimensionless form, which is a function of Reynold number $\left(\frac{\mu}{H^{3/2}\ \rho g^{1/2}}\right)$ viscous effect, weber number $\left(\frac{\sigma}{\rho g\, H^2}\right)$ surface tension effect .in practical situations, the Reynold number and, weber number effects are negligible [8]. And equation (3) can be rewritten as:

$$\frac{q}{g^{1/2}\,H^{3/2}} = f_2 \left(\frac{R}{H}\right) \dots\dots\dots\dots\dots\dots\dots\dots (4)$$

When the weir crest is equal to (L=π*R).The dimensional analysis indicate that the flow rate per unite width is proportional to $\sqrt{g}$, $H^{3/2}$ and by the parameter (R/H).since the discharge equation can be written as[9] :

$$q = C_d\ \sqrt{g}\, H^{3/2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (5)$$

The above equation developed for flow passes through the critical depth, thus the discharge coefficient may be express as:

$$C_d = f_3 \left(\frac{R}{H}\right) \dots\dots\dots\dots\dots\dots\dots\dots (6)$$

3. EXPERIMENTAL WORK:

The experiments of this study were carried out in recirculating Plexiglas laboratory channel, with (5m) long, (0.076m) width, and (0.15m) depth .The channel is supplied with a constant head tank. The flow rate was measured by volume - time method. The water surface profile was measured by using point gauge. A semicircle crested weir of (4cm) radius manufactured from timber with smooth surface placed at a distance (3.85m) downstream outlet of the tank and fixed directly on side walls. The discharge measuring started from maximum value (Q=1.098l/s) with successive reading to minimum value (Q=0.62l/s) with the corresponding upstream head over the weir crest as well as the measuring of flow depths along channel. All experiments done with zero slope channel bed. Photograph was taken during the experiments and used to visualize the flow pattern as shown in Figure (2).

3.1 HEAD-DISCHARGE RELATIONSHIP:

The most important advantage of the broad crested weir is accurately calibrated according to empirical relationship. With the aid of Laboratory experimental tests the empirical discharge coefficients could be computed by using the discharge equation for any meter which in the following forms [11]:

$q = KH^m \dots\dots\dots\dots\dots\dots\dots\dots\dots (7)$ Where K and m are weir coefficients

An empirical formula describing the discharge – head relationship by using a power fit or trend in Excel (Use a spreadsheet) is:

$$q = 1.8216\, H^{1.5} \dots\dots\dots\dots\dots\dots (8)$$

The graphical representation of head – discharge equation is shown in Figure (3).

4. RESULTS AND DISCUSSION:

4.1 ANALYSES OF EXPERIMENTAL DATA:

Statistical analysis and Equation (4) can be represented as, following:

$$\frac{q}{g^{1/2}H^{3/2}} = \psi \left(\frac{R}{H}\right)^{a} \dots\dots\dots\dots\dots (9)$$

The above equation is solved by using none linear regression analysis and solver function in Microsoft excel and the constants (ψ, a) are evaluated and the following relationship is obtained:

$$\frac{q}{g^{1/2}H^{3/2}} = 0.577\left(\frac{R}{H}\right)^{0.144} \dots\dots\dots\dots\dots(10)$$

A graph drawn between the computed discharge using the equation (10) and the experimental discharge is as shown in figure (4). The squared deviation (residual) between the computed discharge and the experimental data which was actually measured is, calculated the matching between the computed discharges and the actual data. Our objective is to reduce these square deviations as much as possible. The sum of all these square deviations should be decreased to a small value which represent the objective in excel solver function. Minimization, and the changing cell in solver function box are the parameters (ψ) and (a). A report of solver function shown in appendix (A). The coefficient of correlation between experimental and computed discharges is found as (0.97). This coefficient justifies the selection of the independent parameter.

Based on equation (6) a regression analysis in Microsoft excel used to correlate (C_d) with (R/H) can be written in an empirical relation as:

$$C_d = 1.966\left(\frac{R}{H}\right)^2 - 2.958\left(\frac{R}{H}\right) + 1.912 \quad \dots\dots\dots\dots (11)$$

Graphical representation of equation (11) shown in figure (5).With a correlation coefficient of (R^2 = 0.86), the relation between C_d values predicted by equation (11) and Experimental values of Cd is plotted in figure (6) showing a good agreement. The C_d values based on direct measurements increased continuously from 0.81 at R/H=1.25 to high value of 0.89 at R/H=1.03. Experimental studies by Al Babely [(3)] on cylindrical crested weir indicate that , decreases in radius to head ratio R/H values lead to increases in coefficient of discharge (C_d) value, since the circular crested weir will behave as a sharp crested weir when the head is relatively large compared to crest radius.

4.2 HEC-RAS PROGRAM:

There are several methods available to view HEC-RAS output, including cross-section profiles, perspective plots, and data tables. Summary tables are used to show a limit number of hydraulic variables for the main channel stations, the details of hydraulic parameter for a selected station (1.1) for the rang of discharges are shown in appendix (B).

4.2.1 MODEL CALIBRATION PROCESS:

The calibration process of (the cross-section) model was constructed by calibrating the backwater model to observed water levels for various flows. The key parameter which is adjusted in the calibration phase is the hydraulic roughness or Manning's "n" of the cross section to show a match between observed and computed water surface profiles for a given flow [(12)]. "The calibration involved checking the alignment of the actual water surface with modelled HEC-RAS profile as shown in figures. (7a to 7e)

4.2.2 HEAD-DISCHARGE RELATIONSHIP:

After the calibrations the simulation results with a selected Manning's (n) are plotted versus the measured water level, figure (8).The modelled rating curve is about (+1.2%)of the observed rating curve at the high stage flow.

5. CONCLUSION:

1) The advantage of using 1- dimensional HEC-RAS that is easy to use, and demands few boundary conditions data.

2) HEC-RAS presented precise results of the head discharge relationship for the semi-circle crested weir.
3) The Manning roughness coefficient is the most calibrating parameter and its value can change the results significantly.
4) The flow upstream the weir is subcritical, Then critical flow occurs on weir crest, and the flow along downstream weir is supercritical.
5) The location of the control section, critical depth, is not constant, but varies with discharge.
6) The relationship between discharge coefficient (C_d) and head to weir radius ratio was found. For the same weir height, the increase in head to weir radius ratio leads to increase in (C_d) value
7) The weir coefficients for semicircle weir is greater than the basic broad crested weir coefficient.
8) The critical flow depth is approximately located at the crest section.
9) The results show a significant difference in water surface elevation in the downstream weir portion.

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Table (1): List of symbols

a	Constant (dimensionless)
g	Gravity acceleration (m^2/s)
H	Head up stream weir crest (m)
K	Weir coefficient ($m^{1.5}/s$)
L	crest Length of weir (m)
m	Head exponent (m)
n	Manning roughness coefficient
Q	Discharge (m^3/s)
q	Discharge per unit width ($m^3/s/m$)
R	Radius of the circular crested weir (m)
V	Velocity (m/s)
X	Horizontal distance (m)
y	Flow depth (m)
Z	Bed Elevation (m)
ψ	Constant (dimensionless)
F_r	Froud number
C_d	Discharge coefficient (dimensionless)
Δx	Horizontal distance between two cross sections (m)
R^2	Correlation coefficient (dimensionless)
ρ	mass density of the fluid (kg/m^3)
μ	dynamic viscosity (N/m^2. s)
σ	surface tension (N/s)
α	kinetic Energy coefficient
EG	Energy grade line (m/m)
OWS	Observed water surface (m)
WS	Water surface (m)

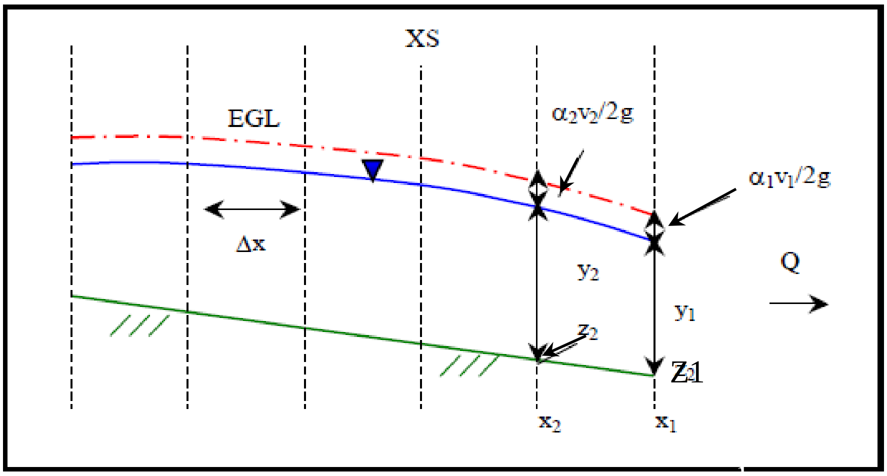

Figure (1).standard step method [6]

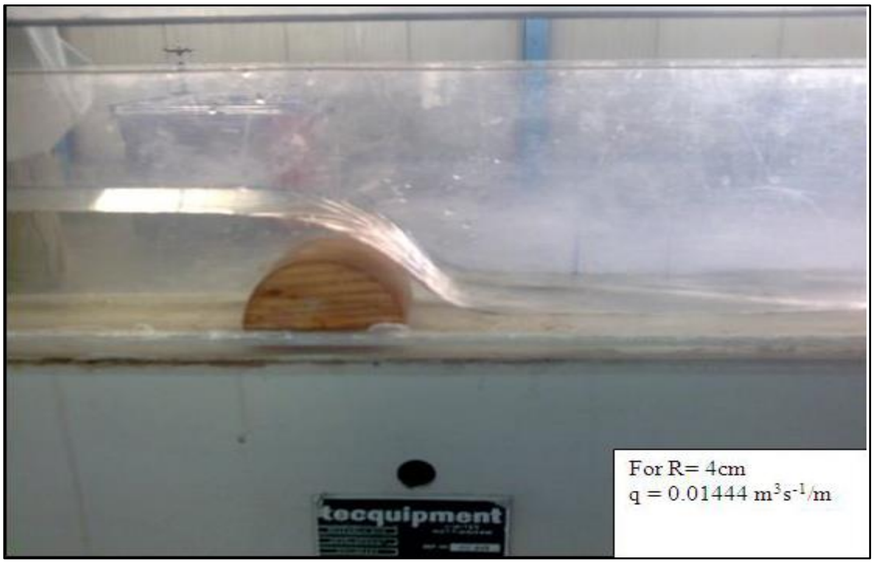

Figure (2).flow pattern over the weir [10]

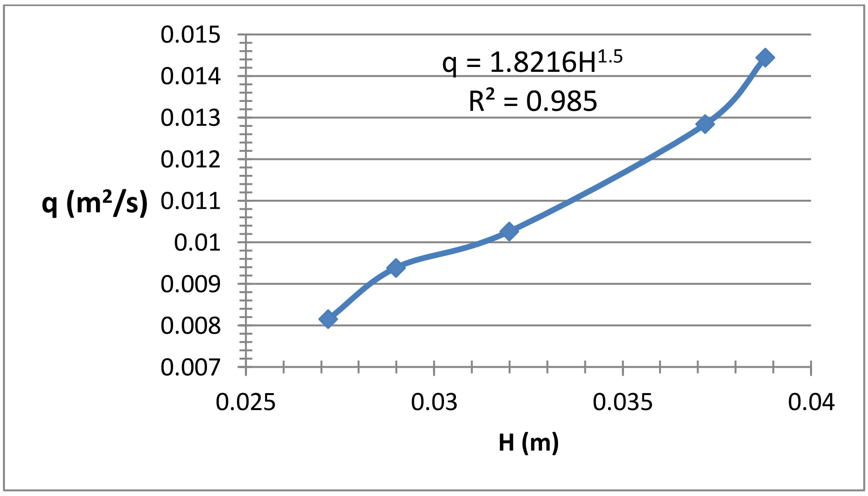

Figure (3).relationship between (q) and (H)

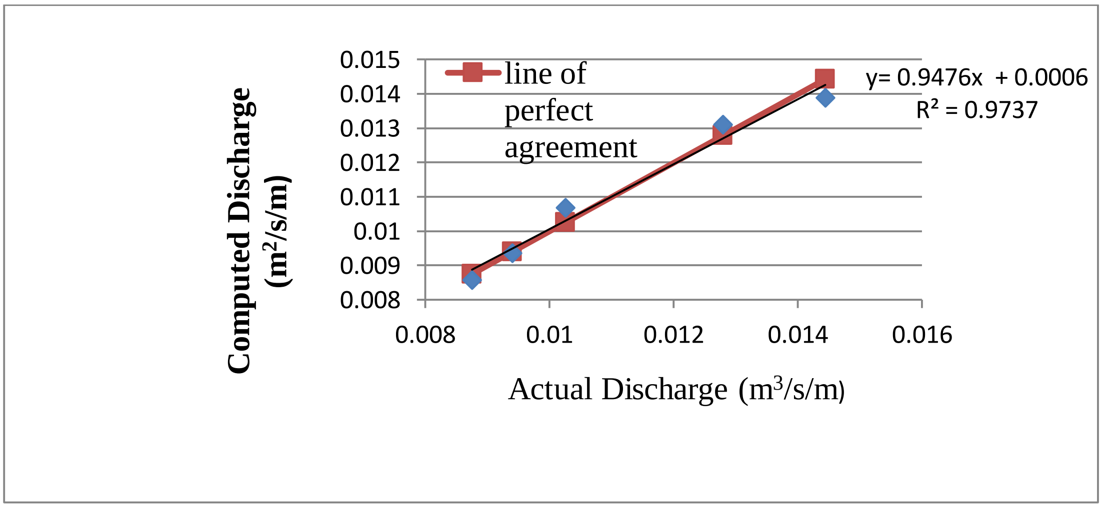

Figure (4).Actual versus computed discharge

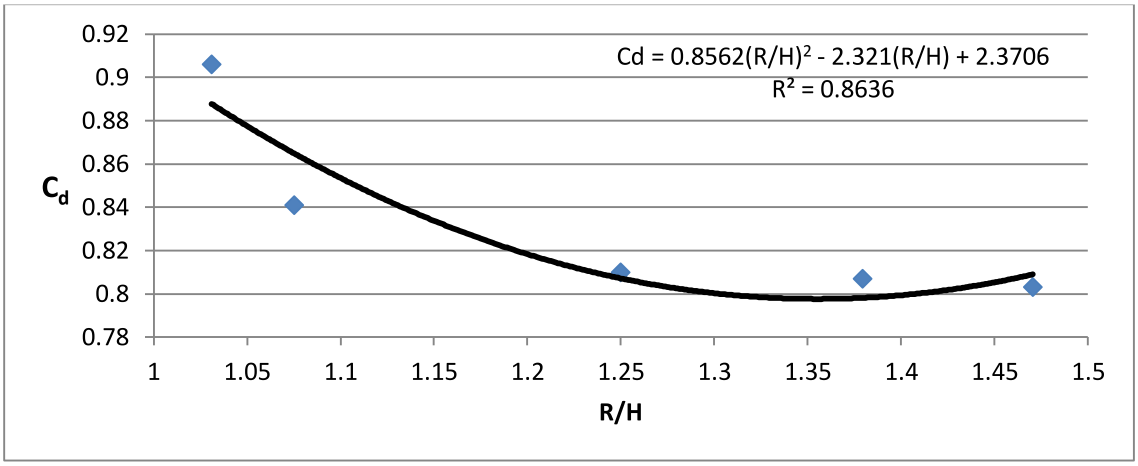

Figure (5).Discharge coefficient versus (R/H)

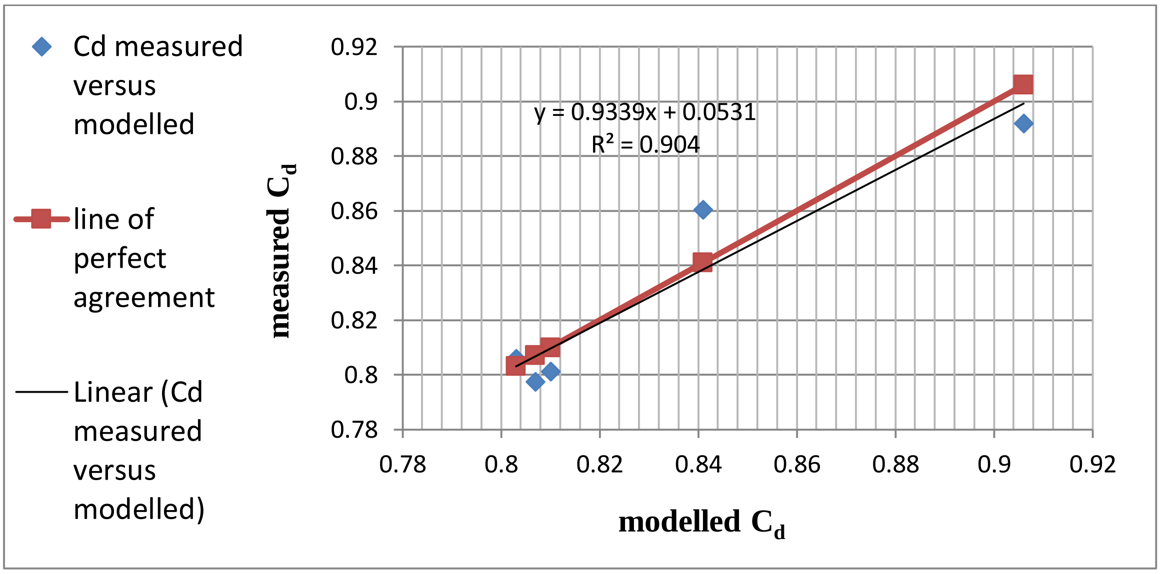

Figure (6).Actual versus modelled C_d

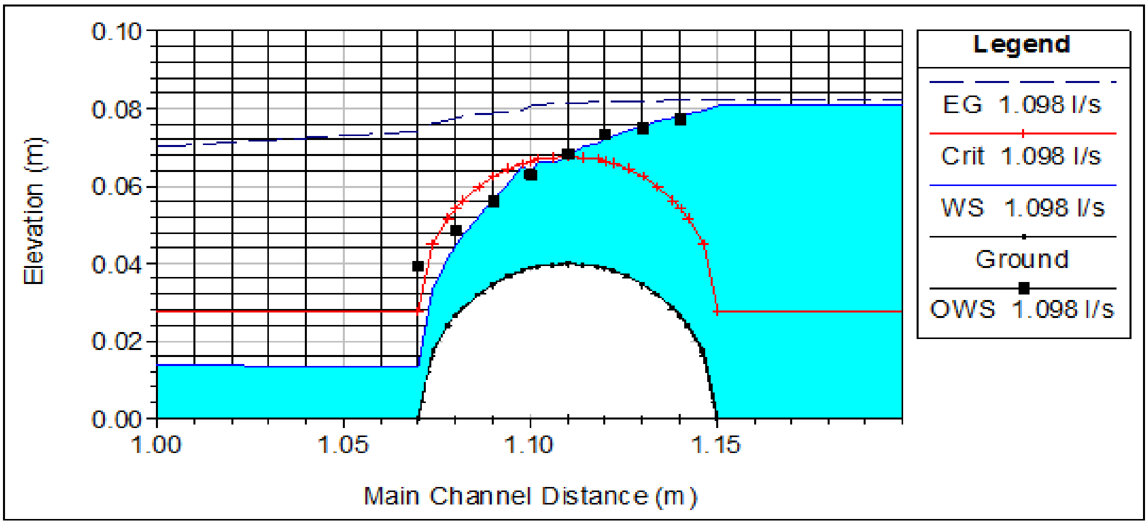

Figure (7a).Water surface profile (Q=1.098 l/s)

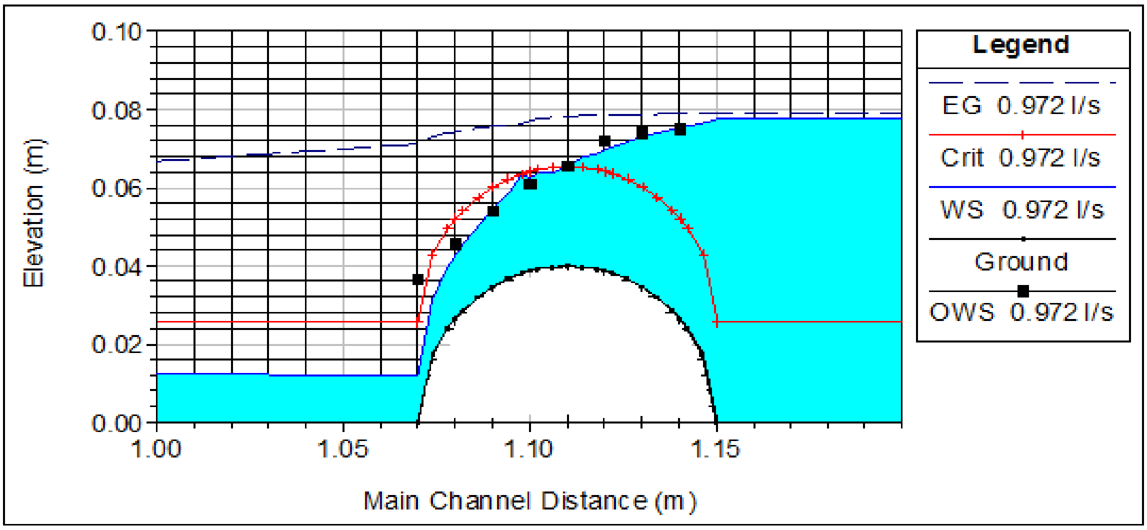

Figure (7b).Water surface profile (Q=0.972 l/s)

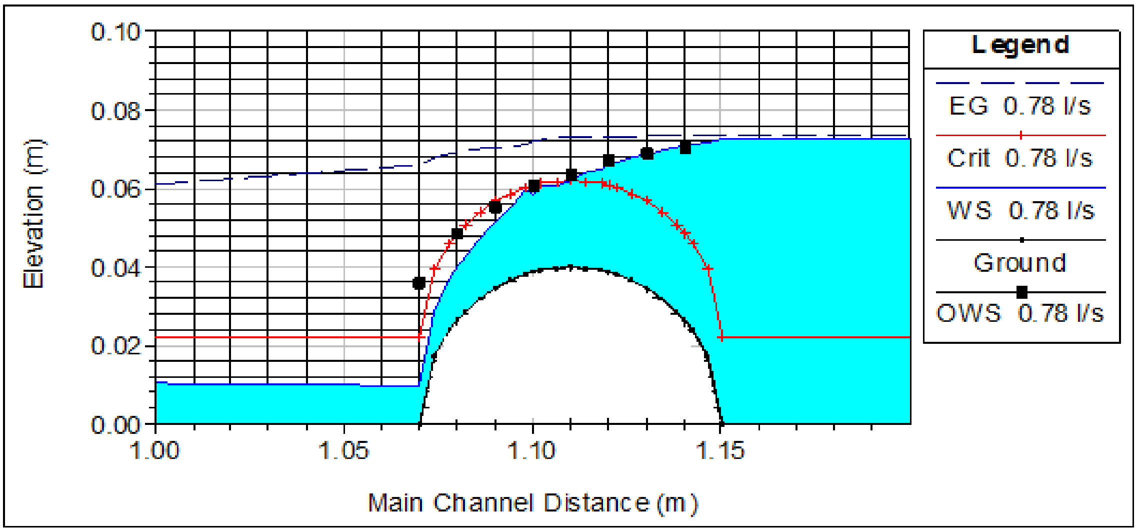

Figure (7c).Water surface profile (Q=0.78 l/s)

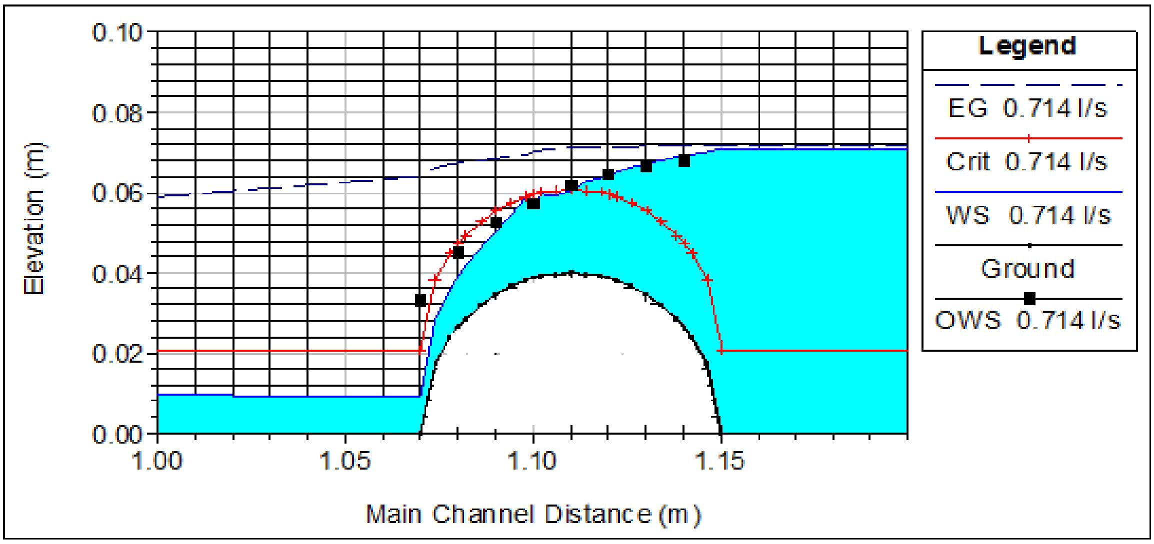

Figure (7d).Water surface profile (Q=0.714 l/s)

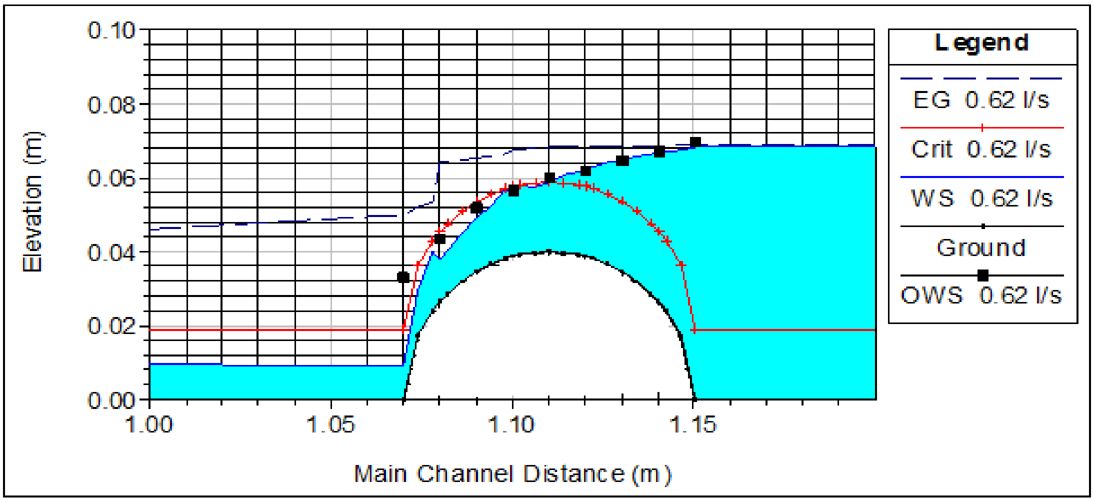

Figure (7e).Water surface profile (Q=0.62 l/s)

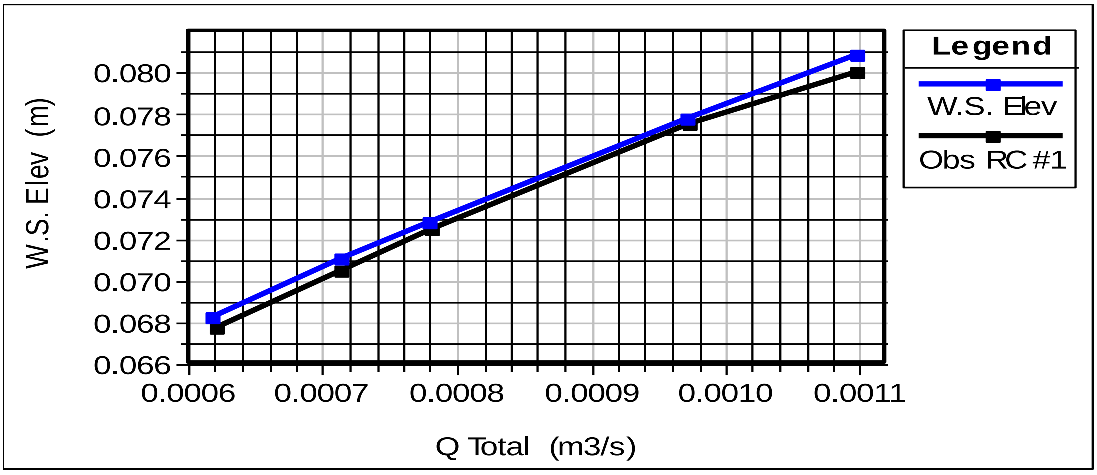

Figure (8).Measured and modelled values of head –discharge relationship

Appendix (A)

Microsoft Excel 14.0 Answer Report
Report Created: 16/06/2016 12:17:48 ص
Result: Solver has converged to the current solution. All Constraints are satisfied.
Solver Engine
Solver Options
Objective Cell (Min)

Cell	Name	Original Value	Final Value
$G$5	SSD	0.000193711	4.81518E-14

Cell	Name	Original Value	Final Value	Integer
$D$2:$D$6				

NONE

Appendix (B)

River	Reach	RiverSta	Profile	Q Total (m^3/s)	Min Ch El (m)	W.S. Elev (m)	CritW.S. (m)	E.G. Elev (m)	E.G. Slope (m/m)	Vel Chnl (m/s)	Flow Area (m^2)	Top Width (m)	Froude # Chl
Flum	canal	1.11	1.098 l/s	0.001098	0.03993	0.06758	0.06758	0.081526	0.00491	0.523216	0 .00210	0.07590	1.00437
Flum	canal	1.11	0.972 l/s	0.0009713	0.03993	0.06542	0.06542	0.078260	0.00482	0.502064	0.00193	0.07590	1.00379
Flum	canal	1.11	0.78 l/s	0.0007787	0.03993	0.06194	0.06194	0.073010	0.00469	0.466213	0.00167	0.07590	1.00313
Flum	canal	1.11	0.714 l/s	0.0007136	0.03993	0.06068	0.06068	0.071139	0.00465	0.453072	0.00157	0.07590	1.00392
Flum	canal	1.11	0.62 l/s	0.0006173	0.03993	0.05878	0.05878	0.068264	0.00459	0.431565	0.00143	0.07590	1.00344

Appendix (C) [3]

Experimental Data

Laboratory measurement for model (I) with (R = 4 cm) (the measured at equal distance of (1 cm) from the center line)

Q (l/s)	Upstream											C.L	downstream										
1.098	7.88	7.88	7.88	7.88	7.88	7.83	7.7	7.63	7.49	7.35	7.1	6.83	6.27	5.6	4.85	3.94	3.09	2.3	1.8	1.59	1.45	1.4	1.25
0.972		7.72	7.7	7.68	7.6	7.55	7.5	7.4	7.21	7.1	6.89	6.54	6.09	5.4	4.55	3.67	2.67	1.98	1.5	1.27	1.2	1.12	1.12
0.78		7.2	7.2	7.2	7.2	7.2	7.2	7.1	7.04	6.9	6.7	6.35	6.08	5.53	4.86	3.61	3.46	1.68	1.2	1	1	0.92	
0.714			6.9	6.9	6.9	6.9	6.9	6.86	6.8	6.63	6.46	6.19	5.73	5.25	4.5	3.3	2.1	1.36	0.9	0.86			
0.62			6.72	6.72	6.72	6.72	6.72	6.72	6.62	6.46	6.2	6	5.64	5.18	4.32	3.3	1.9	0.99	0.84	0.75			

نمذجة جريان احادي البعد لتصريف فوق سد غاطس نصف دائري الحافة بأستخدام برنامج (HEC-RAS)

الخلاصة

تم في هذا البحث استخدام سد غاطس ذو حافة نصف دائرية موضوع على عرض القناة المختبرية (غير مقلص) في قياس معدل الجريان المار عبر السد والشحنة في مقدم السد الغاطس تحت ظروف جريان حر. من خلال هذه النتائج المختبرية تم ايجاد معادلة تجريبية ما بين التصريف و الشحنة المقاسة. بأستخدام طريقة التحليل البعدي تم ايجاد علاقة مابين المتغير المستقل (R/H) الذي يمثل (التقوس النسبي للحافة) و المتغير المعتمد اللابعدي $\frac{q}{g^{1/2}H^{3/2}}$. وبتطبيق طريقة الانحدار المتعدد في برنامج المايكروسوفت اكسل تم ايجاد معادلة لحساب التصريف الذي يمثل المتغير المعتمد والمتغيرات المستقلة المؤثرة في الجريان ومعادلة لحساب معامل التصريف بدلالة المتغير المستقل (R/H).تم تشغيل برنامج (HEC–RAS) لحالة الجريان الثابت و حساب المقاطع الطولية ومنحني المعايرة والعمق الحرج للجريان والتحقق من نتائج البرنامج عند المقارنة مع القراءات المختبرية والتي اظهرت عن توافق جيد .ان معامل السد ذو الحافة النصف دائرية هو اكبر من معامل السد العريض الحافة وهنالك انتقال للجريان من جريان تحت الحرج في مقدم السد الى جريان فوق الحرج في مؤخرة السد مارا بالحالة الحرجة في قمة السد ضمن حدود الحريان الحر.