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# Experimental Study of Discharge with Sharp-Crested Weirs

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***Abstract*****—**In this study the water flow in an open channel over a sharp-crested weir is investigated experimentally. For this reason a series of laboratory experiments were performed in an open channel with a sharp-crested weir. The maximum head expected over the weir, the total upstream water height and the downstream water height of the impact in the constant bed of the open channel were measured. The discharge was measured using a tank put right after the open channel. In addition, the discharge and the upstream velocity were also calculated using already known equations. The main finding is that the relative error percentage for the majority of the experimental measurements is ± 4%, meaning that the calculation of the discharge with a sharp-crested weir gives very good results compared to the numerical results from known equations.

***Keywords*****—**Sharp-crested weir, weir height, flow measurement, open channel flow.

## I. Introduction

WEIRS are commonly used for measuring the flow rate in an open channel. The measurement of the height of the flowing water above the top of the weir can be used to determine the flow rate. Many researchers have experimentally studied the flow of the downstream free-fall water on a bed [13], [14]. The type of bed usually being used was either of loose or solid material. Apart from this difference in materials, there is a wide variety in the form of flow before the free-fall water. The upstream flow can be water vein under pressure, weir, hole etc.

The sharp-crested weirs are simple hydraulic technical constructions in open channels, put vertical to the flow and mainly used for the discharge measurement. Many researchers have already studied the flow downstream of the weirs, under various conditions. Moore [1], for example, performed laboratory experimental measurements in a rectangular negative step with a subcritical upstream flow. He thoroughly studied the energy losses, the special energy and the static pressure of the bed downstream of the negative step, while the depth of water under the flow vein was calculated using the amount of motion equation.

Kandaswamy and Rouse [2] performed an experimental study to define the velocity and pressure distribution over a weir at the highest point of the free surface of the water vein. On the other hand, Vickery [3] studied the flow over a weir, measuring the water depth under the water vein. Vickery, based on the results of the experiments done, suggested an empirical relationship between the water depth and the weir height.

In their study, Rajaratnam and Muralidhar [4] presented an experimental work for the calculation of the discharge coefficient and the velocity profiles over a sharp-crested weir. These calculations are very useful for the eventual development of a theory for curvilinear open channel flow.

Numerical and experimental studies of flow over weirs were performed to understand the flow characteristics of these weirs as well as the determination of the coefficients of discharge under free and submerged flow conditions [5].

The concept of a slit weir suitable for measuring small discharges with high accuracy due to the increased head over the weir was introduced by Aydin et al. [6]. The most important characteristic of the slit weir is the independence of the discharge coefficient from the channel width, because of the completely contracted nature of the flow over the weir. A study flow over a rectangular sharp-crested weir was presented by Rady [7]. A 3D numerical model has been used for evolving a relationship to estimate the discharge coefficient for rectangular sharp-crested weirs. This study showed that the important variable governing discharge over sharp-crested weirs is $H_t/t_w$ ($H_t$: total head upstream from the weir, $t_w$: height of the weir).

The study of Gharahjeh et al. [8] focuses on the experimental investigation of various possible formulations of the weir velocity for available weir heights and widths. For this purpose, regression analyses along with the multivariate optimization technique have been utilized to reach the objective of the study. The flow behavior of different sharp crested weirs was thoroughly studied by Ramakrishna et al. [9]. Their main conclusions were: a) for low discharge with high accuracy a triangular sharp crested weir can be used to measure the flow; b) for high discharge with considerable accuracy a rectangular sharp crested weir can be used to measure the flow; and c) for high discharge and less accuracy a trapezoidal and sharp-crested weir can be used to measure the flow

Finally in the study of Gong et al. [10], a series of experiments were performed to study the hydraulic characteristics of flow over a round-crested weir. Experimental results showed that the rounded upstream corner could increase the discharge capability with the discharge capability increasing with increases in the round ratio.

The purpose of present work is to study the water flow over a sharp-crested weir along with the impact of a constant bed. The total upstream water height, the shape of the front water, the downstream water height of the impact in the constant bed of the channel and the discharge are being studied.

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## II. Experimental Procedure: Measurements

For the realization of the experiments, an open channel located in the Laboratory of Hydromechanics and Environmental Engineering, Civil Engineering Department, University of Thessaly was used. The open channel is rectangular with smooth bed and walls are made of Plexiglas. It is a horizontal open channel of 7 m length, 0.10 m width and 0.275 m height. At the down end of the channel there is a sharp-crested weir. This weir placed in an open channel consists of a vertical flat plate with a sharp edge at the top (the crest), forcing the liquid to flow over the crest in order to drop into the pool below the weir. Fig. 1 shows a longitudinal section of the open channel at the point where the sharp-crested weir is located, representing the flow over it.

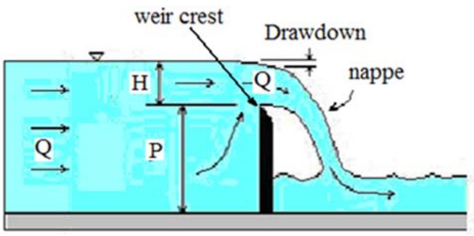


Fig. 1 Flow over a sharp-crested weir

In Fig. 1, H is the maximum head expected over the weir and P (P = 0.158 m) is the height of the weir above the channel invert. Drawdown flow conditions occur upstream of the weir. This is due to the increased velocity of the water when the water approaches the weir.

The water with the help of a pump and a suitable piping system is driven to the canal originating from an underground tank. The willing reduction of the discharge is being achieved utilizing a circular valve. Downstream of the channel there is a tank in which the water is driven to calm the flow (equilibrium tank). There is also another tank, on one side of which, there is a v-notch weir (Fig. 2). To calculate the discharge with a sharp-crested weir, the Kindsvater-Carter equation [11] is used:

$$Q = 4.28C_e \tan(\frac{\theta}{2})(H + k)^{2.5} \quad (1)$$

where Q is the discharge over the weir, $C_e$ is the effective discharge coefficient, H is the head over the weir, k is a head correction factor, θ is the angle of the V-notch (during the experiments of the present study $\theta = 90^0$).

The equations for the calculation of $C_e$ and k are [12]:

$$C_e = 0.607165052 - (0.000874466963)\theta + (6.10393334x10 - 6)\theta^2 \quad (2)$$

$$k = 0.0144902648 - (0.00033955535)\theta + (3.29819003x10 - 6)\theta^2 - (1.06215442x10 - 8)\theta^3 \quad (3)$$

From (2) & (3), with $\theta = 90^o$: Ce = 0.57790489 and k = 0.00088468713. The discharge Q is being calculated using [12].

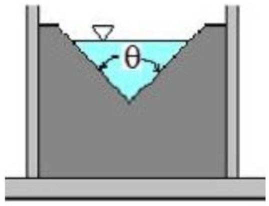


Fig. 2 V-notch weir

Experiments were carried out for ten different H heights over the weir. The maximum head expected over the weir (H), the total upstream water height ($H_0$) and the downstream water height of the impact ($H_3$) were measured. The discharge Q and the upstream velocity U were calculated. A is the area of cross section over the weir [A = 0.10 (m) X H (m)]. The discharge $Q_0$ is measured by a tank near the open channel from the relationship:

$$Q_0 = \frac{V}{T} \quad (4)$$

where V is the volume of the tank and T the time needed for the tank to be filled. Table I presents the flow characteristics.

TABLE I
Flow Characteristics

| H (m) | $H_0$ (m) | $H_3$ (m) | Q X $10^{-3}$ ($m^3/s$) | U=(Q/A) (m/s) | $Q_0$ X $10^{-3}$ ($m^3/s$) |
|---|---|---|---|---|---|
| 0.036 | 0.194 | 0.012 | 0.357 | 0.099 | 0.350 |
| 0.048 | 0.206 | 0.013 | 0.722 | 0.150 | 0.700 |
| 0.056 | 0.214 | 0.016 | 1.054 | 0.188 | 1.030 |
| 0.062 | 0.220 | 0.019 | 1.354 | 0.218 | 1.330 |
| 0.068 | 0.226 | 0.022 | 1.701 | 0.250 | 1.650 |
| 0.076 | 0.234 | 0.025 | 2.238 | 0.294 | 2.190 |
| 0.082 | 0.240 | 0.027 | 2.701 | 0.329 | 2.750 |
| 0.088 | 0.246 | 0.029 | 3.216 | 0.365 | 3.310 |
| 0.093 | 0.251 | 0.031 | 3.688 | 0.397 | 3.830 |
| 0.097 | 0.255 | 0.033 | 4.093 | 0.422 | 4.260 |

## III. Analysis of Results

From the experiments it is obvious that an increase of the upstream load results in a reduction of the curvature of the water vein. This is due to the fact that the greater quantity of water blows away the water vein resulting in a reduction of the curvature. In addition to this, as the quantity of the water increases, the distance of its impact on the bed gets bigger.

From Table I, it is obvious that the downstream water depth $H_3$ increases as the upstream load increases. This is due to the fact that the increase of the quantity of water blows away the water vein resulting in an increase of the downstream water height.

Fig. 3 presents the velocity profile with the maximum head expected over the weir H. As it can be seen from this figure, all the data set have a similar curvature for the whole range of water height H.

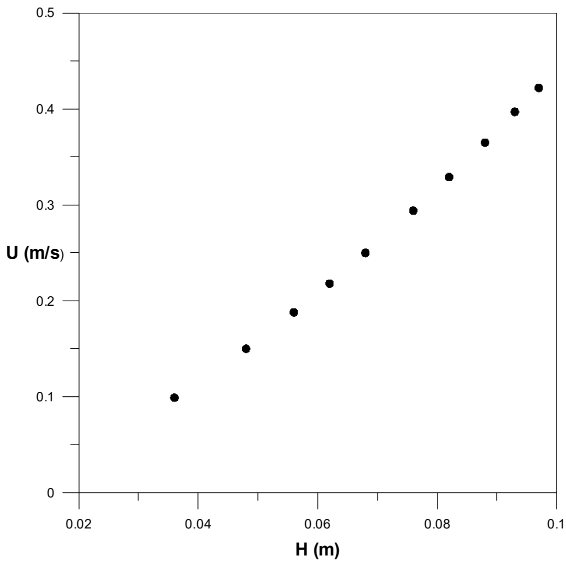


Fig. 3 Velocity profile versus maximum head expected over the weir

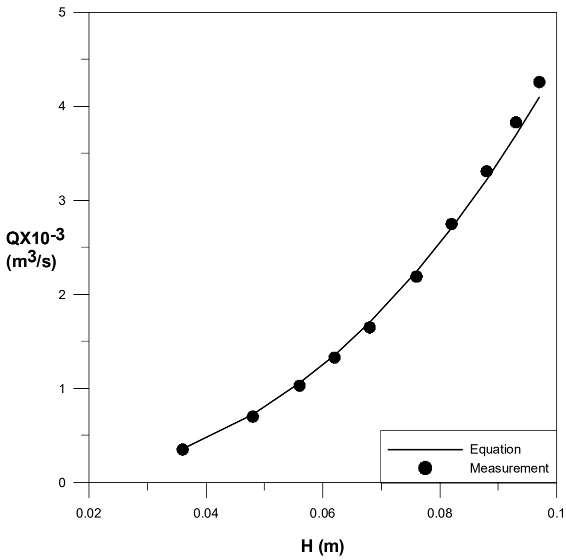


Fig. 4 Measured discharges compared to calculated discharges using equation

Fig. 4 compares the measured discharges with discharges calculated using (3). As it can be seen from what Fig. 4 presents, the values resulting from (3), representing the data points, are almost identical to the experimental ones, bearing in mind that (3) is by far simple and compact compared to the respective equations proposed by earlier studies as presented in the literature review. Small differences appear when greater values of upstream height are involved. This is due to the fact that the increase of the upstream height creates more turbulence and for this reason the results from (3) have lower values compared to the measured ones.

The relative error percentage between the experimental data and the calculated values through (3) are plotted in Figs. 5 and 6. The relationship is:

$$\% \, error = \frac{Measured - Calculated}{Measured} \text{ X100\%} \tag{5}$$

It is observed that the relative error percentage for the majority of the data points is ± 4%, meaning that the calculation of the discharge with a sharp-crested weir gives very good results compared to the calculated discharges using (3). Fig. 6 shows that small differences (up to ± 4%) appear in the greater values of upstream height.

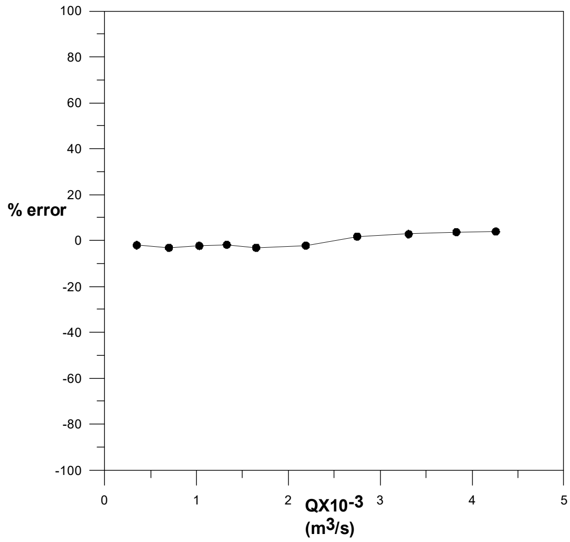


Fig. 5 Relative error percentage (±100%) of the power function with respect to measured discharge

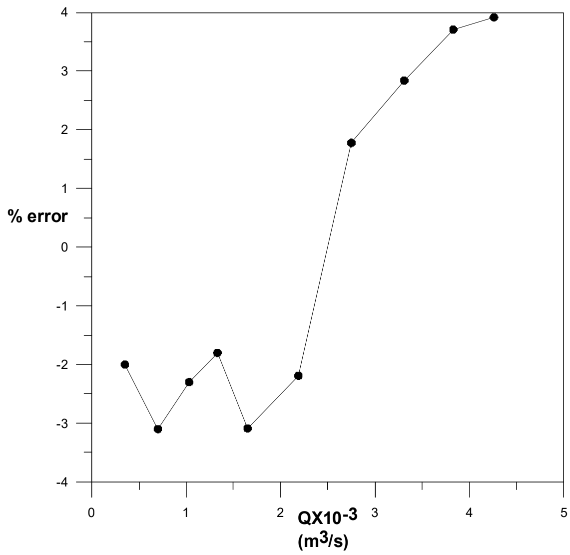


Fig. 6 Relative error percentage (±4%) of the power function with respect to measured discharge

## IV. Conclusions

In this experimental work the study of the water flow above a sharp-crested weir which impacts in a constant bed was presented.

The main conclusions of this study are: a) increase of the upstream load results in a reduction in the curvature of the water vein and in an increase in the distance of its impact on the bed; b) the downstream water depth $H_3$ increases with the increase of the upstream load; c) all the data set have a similar curvature for the whole range of upstream height; and d) there is a good agreement between measured and calculated discharges proving that the calculation of the discharge with a sharp-crested weir provides very satisfying results.

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