FLOW OVER WEIRS WITH PRACTICAL PROFILE

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ABSTRACT

The study of the characteristics of flow over weirs with practical profile leads to better utilization in the practice of Hydraulic structures. In the present study; the velocity coefficient C_v, the flow depth at the toe of the weir h, and the discharge coefficient C_d are experimentally investigated. Empirical formula is developed to estimate the coefficient C_v. Two solutions are demonstrated to calculate the depth of flow at the toe. The first method is based on the energy equation, whereas the second is based on the dimensional analysis consideration. The inclination of both upstream and downstream faces of the weir showed remarkable effect on the discharge coefficient. Accordingly, charts to determine the discharge coefficient for different slopes are given.

NOTATIONS

- b — Width of the weir crest;
- C_d — Discharge coefficient of the weir, $C_d = q/\sqrt{2g}\, H_o^{3/2}$;
- C_v — Velocity coefficient, $C_v = q/h\,\sqrt{2g\,(E_o - h)}$;
- E_o — Total energy, $E_o = P + H_o$;
- g — Gravity acceleration;
- H — Head acting on the weir;
- H_o — Total head on the weir, $H_o = H + \dfrac{q^2}{2g(P+H)^2}$;
- h — Depth of flow at the toe of weir;
- h_c — Critical depth;
- h_l — Energy loss;
- m_1, m_2 — Vertical projection of the slope of the upstream and downstream faces of weir, respectively;
- P — Height of weir crest;
- q — Discharge per unit width;
- v_o — Velocity of the approaching flow at the weir;
- v — Velocity of flow at the toe of weir.

1. INTRODUCTION

Weirs with practical profile are commonly used in Egypt, specially in Fayoum area. Such weirs are characterized by small heads, and usually with uncontrolled flow.

Weirs with practical profile have trapezoidal cross section, vertical upstream face, and downstream face with 3:2 slope to satisfy the criteria of the most economical section. The width of weir crest b is taken so small so as to violate the condition of the flow over broad crested weir. The above condition is satisfied if the ratio H/b is kept greater than 0.5 [1].

The flow over weir with practical profile simulates the flow over ogee weir. However, the losses in energy of flow over weir with practical profile are higher because of the polygonal shape of the crest. Consequently, the values of the velocity coefficient C_v, the depth of flow at the toe h, and the discharge coefficient C_d for weirs with practical profile differ from the corresponding values in ogee weirs. Various studies of the characteristics of flow over ungated ogee weirs have been listed in reference [2].

The depth of the flow at the weir toe is an important parameter in the hydraulic design of weirs. It influences various downstream conditions, such as; loss of energy, value of Froude number, the formation of the hydraulic jump, and the design of stilling basin. The toe depth is usually obtained by solving the energy equation using trial and error procedure. This procedure does not involve the effect due to the loss of energy, which leads to unaccurate value of the toe depth.

The discharge coefficient is an important parameter in the design and operation of weirs. Wherefore, increasing its value gives better use of these weirs. The discharge coefficient is mainly influenced by the head over the weir H, the width of the weir crest b, and the weir height P. The weir height affects the value of approaching velocity head ($\alpha v_o^2/2g$) which influences the value of the total head H_o. The head over the weir, and the width of crest have remarkable effect on the value of discharge coefficient according to the ratio H/b. For $0.5<H/b<2$, the crest width has a notable effect. When $H/b>2$, the discharge coefficient thoroughly depends on the head H [1,3].

Additional effect on the discharge coefficient may be given by the inclination of the upstream or the downstream faces of the weir. The effect of slope of the weir faces on the discharge coefficient was studied for specific values of H/b [4] or for absolute values of the head H [5]. For weirs of the ogee type, sloping the upstream face results in an increase in the coefficient of discharge for small value of the ratio P/H_o [6].

The present article investigates the effect of sloping of the upstream and downstream faces on the discharge coefficient of weir with practical profile. The study is intended to establish criteria for accurate estimation of the flow depth at the toe of the weir as illustrated in Figure (1).

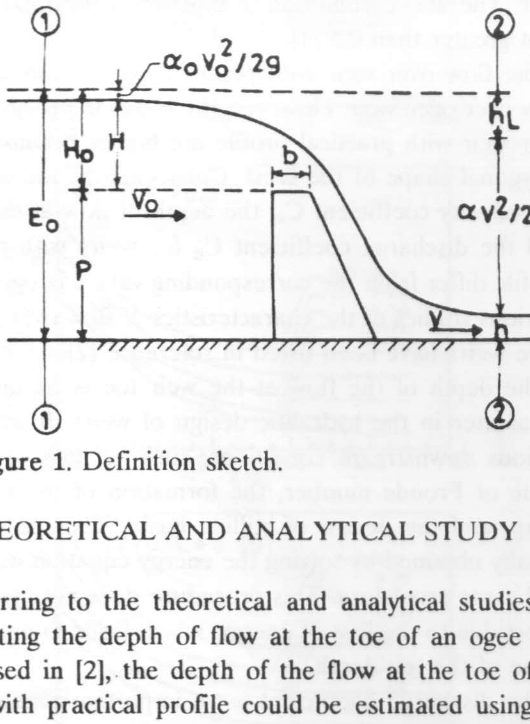

Figure 1. Definition sketch.

2. THEORETICAL AND ANALYTICAL STUDY

Referring to the theoretical and analytical studies for evaluating the depth of flow at the toe of an ogee weir discussed in [2], the depth of the flow at the toe of the weir with practical profile could be estimated using the following two considerations;

1. Applying the energy equation at the two sections 1 and 2, the toe depth is calculated by the equation

$$h = \frac{E_o}{3}\left[1 - 2\cos\left(\frac{\theta}{3} + \frac{\pi}{3}\right)\right]; \tag{1}$$

where

$$\cos\theta = 1 - \frac{6.75}{C_v^2}\left(\frac{h_c}{E_o}\right)^3 \tag{2}$$

2. Applying the π theorem, the toe depth can be related to the head over the weir H, the critical depth h_c, and the weir height P as follows;

$$\frac{h}{H} = f\left(\frac{H^{0.25}\ h_c^{0.75}}{P}\right)^4 \tag{3}$$

3. EXPERIMENTAL ARRANGEMENT

The present experiments were carried out in three horizontal rectangular channels having a width of 19, 40, and 50 cm. The channels are fabricated from 8 mm perespex sheets supported by steel frame. Coated wooden models for the weir were inserted into the channels. Depths of flow were recorded by point gauges. The discharge were measured by a v-notch weir.

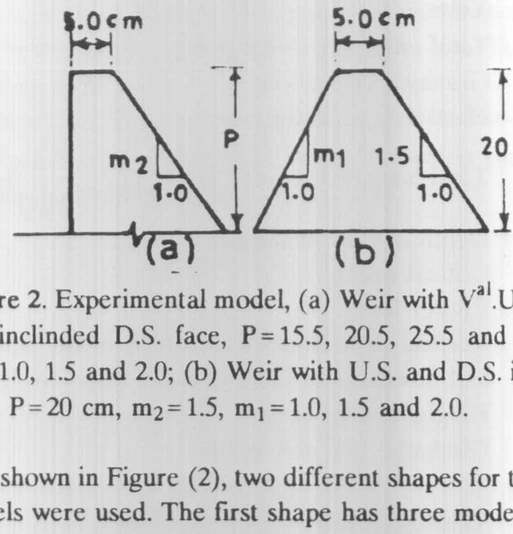

Figure 2. Experimental model, (a) Weir with V^{al}.U.S. face and inclinded D.S. face, P=15.5, 20.5, 25.5 and 30 cm, $m_2=1.0$, 1.5 and 2.0; (b) Weir with U.S. and D.S. inclined faces P=20 cm, $m_2=1.5$, $m_1=1.0$, 1.5 and 2.0.

As shown in Figure (2), two different shapes for the weir models were used. The first shape has three models, each has the same upstream vertical face, and downstream with different face slopes equal to 1:1, 1.5:1, and 2:1. For each shape, different heights P were used of values equal to 30.5, 25.5, 20.5 and 15.5 cm. The second shape has three models of constant downstream face slope equal to 1.5:1, and different slopes of the upstream face equal to 1:1, 1.5:1 and 2:1. A constant height P of 20 cm was used in this case. The width of the weir crest b was taken equal to 5.0 cm for both cases. The passing discharges vary as (40-650), (50-950) and (50-1350) $cm^3/sec/cm$ with respect to channels width 50, 40 and 19 cm, respectively.

4. RESULTS AND DISCUSSIONS

4.1. *The Velocity Coefficient C_v*

To use Eqs. (1) and (2) for calculating the value of the toe depth h, the velocity coefficient C_v has to be known a prior. In the literatures, a general and absolute value of C_v for flow over weir with practical profile was found to be vary from 0.80 to 0.90 [1]. Using an average value of C_v between the above values leads to unaccurate values of the toe depth. Theoretical evaluation of the coefficient C_v is difficult, and it is always obtained through experiments.

The value of the coefficient C_v among other factors is mainly affected by the weir height, and the total head of the weir. Using the experimental measurements for q, H and h for different heights of the weir P, the values of C_v is evaluated from the energy equation,

$$C_v = q/h \sqrt{2g(E_o - h)}.$$

These values are plotted versus the ratio H_o/P for different values of P as shown in Figure (3). Accordingly, empirical equation between C_v and H_o/P could be developed in the form:

$$C_v = 0.9386 + 0.07556 \ln \left(\frac{H_o}{P}\right) \tag{4}$$

Referring to the corresponding equation for flow over ogee weir [2], the values of C_v for weir with practical profile are always lower than the corresponding values for ogee weir for the same ratio H_o/P.

4.2. *The Depth of Flow at the Toe*

Values of velocity coefficient C_v generated from Eq. (4) and the experimental data; P, H_o and h_c were used to calculate the toe depth h using Eq. (1). These values are plotted against the measured ones for different values of P as shown in Figure (4). The figure shows good agreement with a maximum deviation equal to ± 3%.

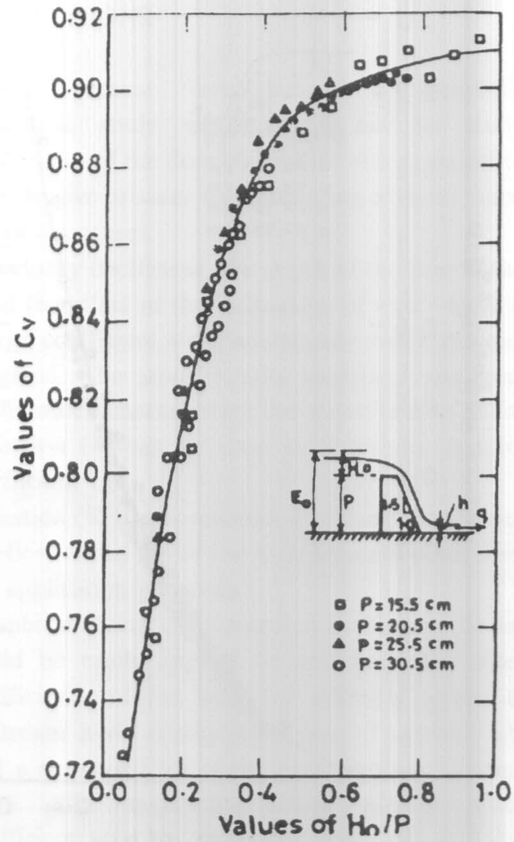

Figure 3. Vairation of velocity coefficient C_v with H_o/P.

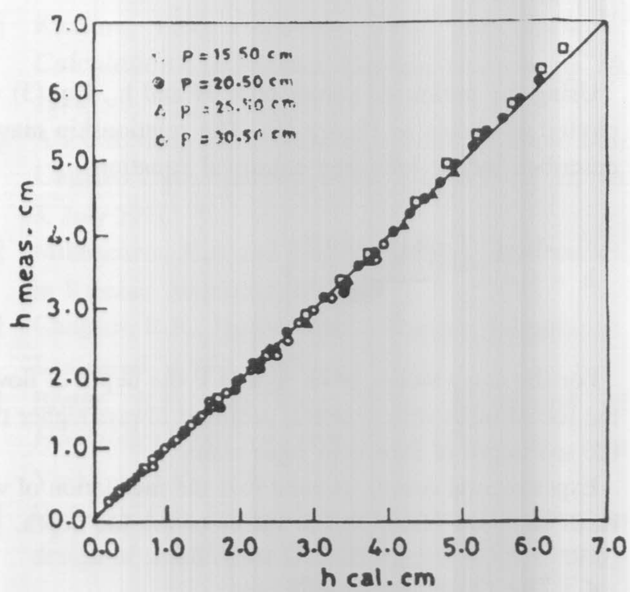

Figure 4. Comparison between measured and calculated values of the toe depth using eq. (1).

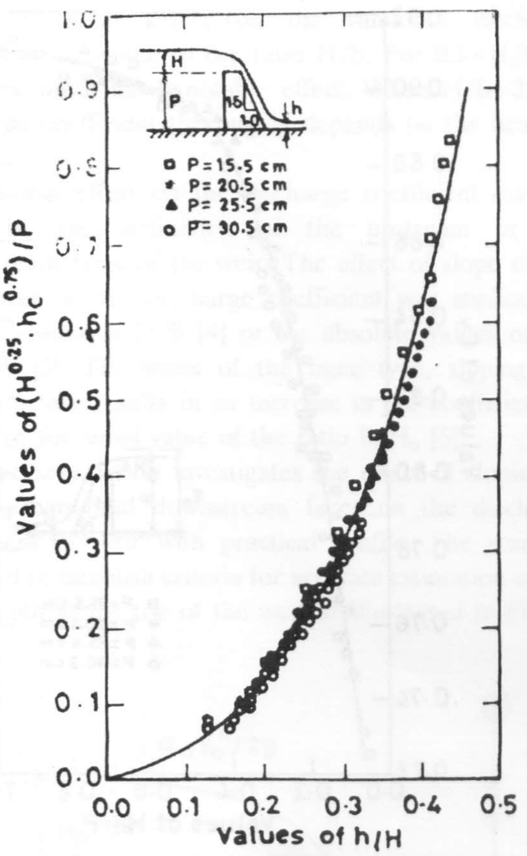

Figure 5. Variation of the toe depth h with acting head H, critical depth h_c ad the weir height P.

Using the measured values of h, H and h_c, Eq. (3) was plotted as shown in Figure (5). The relationship may be described by the following empirical equation

$$h = 0.496\left(\frac{H^{1.113}\ h_c^{0.337}}{P^{0.45}}\right) \tag{5}$$

For the same values of H, h_c and P the depth of flow at the toe of weirs with practical profile is always higher than the toe depth of flow over ogee weirs.

Experimental results showed that the inclination of weir faces has poor effect on the values of the toe depth.

4.3 The Discharge Coefficient

Experiments were conducted in three channels having widths 50, 40, and 19 cm. so as to obtain the value of the discharge coefficient C_d. For any specific height or inclination of the weir face, the final value of C_d is defined as the average of three values obtained from the three channels using the discharge equation, $q = C_d \sqrt{2g}\ H_o^{3/2}$. Comparison between the discharge coefficient obtained using different slopes of the weir faces was achieved by relating the total head H_o to the crest width b, which was kept constant for all models.

The experimental results showed that the inclination of weir faces has considerable effect on the discharge coefficient which may be summarized as follows :

1. The effect of the slope of the downstream face

For this case the experiments were carried out on three models having upstream vertical face, while the slope of the downstream face was taken equal to 1:1, 1.5:1 and 2:1. The average values of the discharge coefficient were computed and plotted versus the relative head ratio H_o/b as shown in Figure (6).

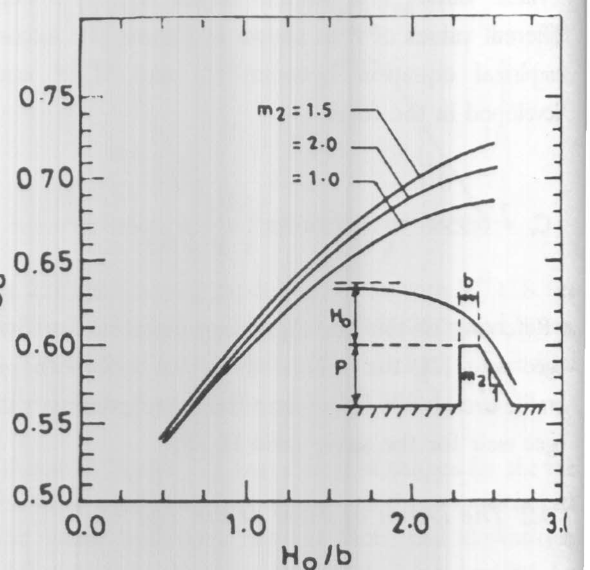

Figure 6. The effect of the D.S. face slope 1:m_2, on the discharge coefficient C_d.

It is clear from the figure that the coefficient C_d decreases as the downstream slope m_2:1 increases. However, this phenomena is violated when m_2 = 1.5 where the coefficient C_d seems to possess an optimal value.

2. The effect of the slope of the upstream face

Three models were used having the same slope for the downstream face (m_2 = 1.5), and upstream face's slope equals to 1:1, 1.5:1 and 2:1. The values of the coefficient C_d were calculated and plotted against the relative head ratio H_o/b as shown in Figure (7).

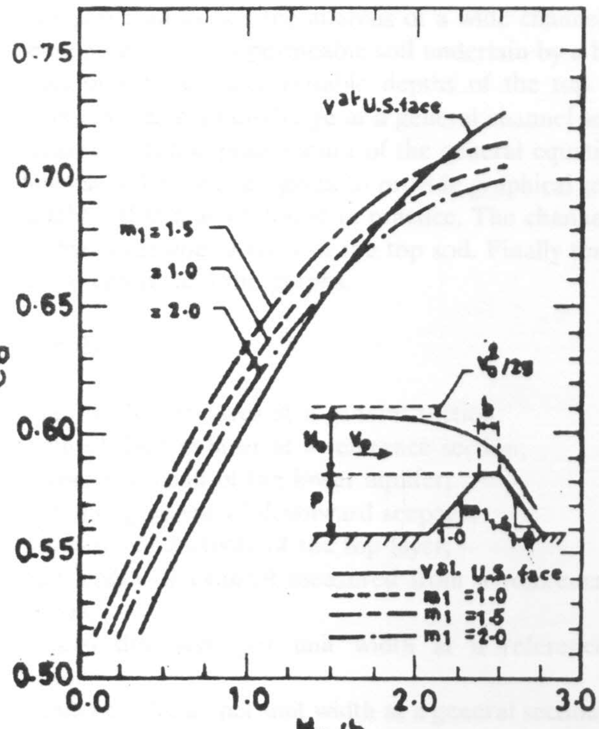

Figure 7. The effect of the U.S. face slope 1:m_1, on the discharge coefficient C_d.

The figure shows that the coefficient C_d increases as the slope m_1:1 decreases, with optimal performance at the slope 1.5:1. A vertical upstream face of the weir gives lower values of the coefficient C_d in the range of $H_o/b < 2$, and higher values when H_o/b is greater than 2. For $H_o/b > 2$, the effect of the crest shape disappears, and the discharge coefficient depends only on the total head H_o.

The optimal effect of the slope 1.5:1 on the discharge coefficient may be related to the fact that this slope makes the shape of the crest closely simulates the shape of the ogee type weir's crest.

5. CONCLUSIONS

In the present investigation, a comprehensive experimental study was carried out to study the characteristics of the flow over weirs with practical profile, in order to give broader understanding of these important hydraulic structures.

The velocity coefficient, the depth of the flow at the weir toe, and the effect of the inclination of weir's faces on the discharge coefficient were analytically and experimentally investigated. The study results analytical and graphical solutions which characterizes the above factors as follows;

1. Equation (4) can be used to determine the velocity coefficient C_v.
2. Equation (5) is recommended to compute the depth of the flow at the toe of the weir because of its simplicity for application purposes.
3. Graphical charts, demonstrated by Figures (6) and (7), could be easily applied to determine the discharge coefficient of the weir for different slopes of the upstream and downstream face. The study showed that a slope of 1.5:1 of the upstream and downstream faces gives maximum values of the discharge coefficient.

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