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Experimental Investigation on Discharge Coefficient of Side Weir in Floodwater spreading systems

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Abstract

Side weirs are widely used to divert flows from rivers, canals, sewers. However, the hydraulic behavior of this type of weir is complex and difficult to predict accurately. Most previous research works for the side weir were carried out in canals with rectangular cross sections and zero weir height. Also in smooth channels with no significant roughness coefficients However, in floodwater spreading systems and most common irrigation systems, canals have trapezoidal cross sections, weir height greater than zero and with nearly rough bed. In this study, the discharge coefficients and overflow discharge over the side weirs was experimentally investigated in a rough-bed flume with manning coefficient of nearly 0.02 under sub-critical condition. Over 20 experimental tests were carried out. The experimental data were compared with other researcher’s formulas and finally a new formula is proposed for prediction of discharge coefficient for side weirs in floodwater spreading systems.

Key words: Discharge Coefficient, Side Weir, Floodwater, Spreading Systems,

1. Introduction

Management of floodwater spreading system essentially depends on accurate flow measurement. Side weirs are essentially weirs installed along the sides of the main channel to divert or spill excess water. In floodwater spreading systems, Side weirs are widely used to divert flows from main channels into, lateral channel. Estimation of discharge over the side-weirs is still an important issue and an ongoing problem in the area of water measurement and especially in floodwater spreading systems. Prior to 1978, most of the studies were focused on the empirical derivation of discharge formulas. In 1934, DeMarchi developed an equation for water profile across a side weir on the assumption that total energy along the side weir is constant. Ackers (1957), Collinge (1957), Frazer (1957), and Subramanya and Awathy (1972) have studied the problems of spatially varied flow over side weirs from a rectangular main channel. Ranga Raju et al (1979) reported that, for their experiments, the specific energy remained nearly constant with the maximum difference being less than 2%. El-Khashab and Smith (1976) reported that the specific energy could decrease by as much as 5% across a side weir in a rectangular channel. There is very limited literature on the discharge capacity of a side weir in a trapezoidal main channel. As mentioned before, most previous researches for the side weir were carried out in channels with rectangular cross sections and zero weir height, also the channels were smooth with no significant roughness coefficients However, floodwater spreading systems and most common irrigation channels have trapezoidal cross sections, weir height greater than zero and with nearly rough bed. Maybe the most important study in a trapezoidal channel was conducted by Cheong (1991). He investigated the discharge capacity of a side opening in a trapezoidal main channel. Figure 1 show the longitudinal profile at side weir under sub-critical condition. The main objective of this investigation is to estimate the lateral outflow from a prismatic trapezoidal main channel for know upstream conditions by using of a side weir. The approach adopted is to formulate a theoretical formula from the experimental data under the following conditions: (1) various upstream subcritical flow conditions; (2) a constant weir height, (3) roughness coefficient of nearly 0.02 for bed materials.

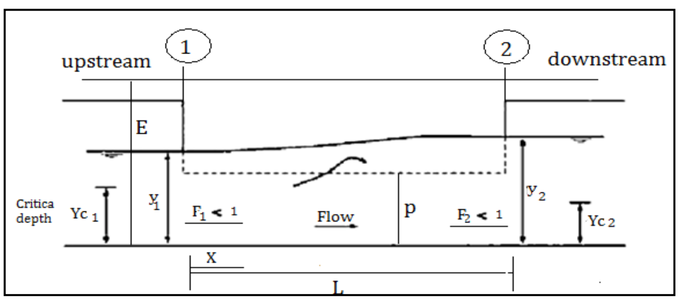

Fig 1a: longitudinal flow profile at a side weir under sub-critical condition

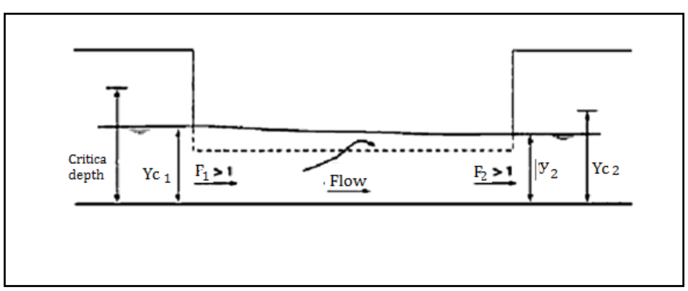

Fig 1b: longitudinal flow profile at a side weir under super-critical condition

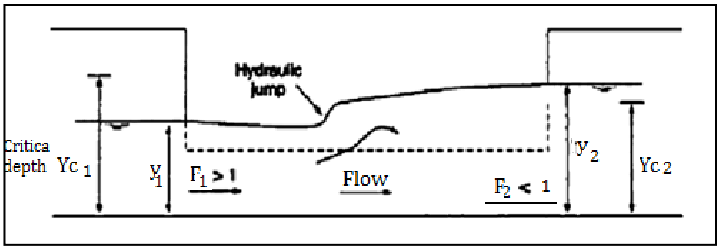

Fig 1c: longitudinal flow profile at a side weir under mixed flow condition

Where, |C_d=discharge coefficient, p=side weir height, Fr_1=upstream Froude number,y_1=depth of flow at section 1,yc_1= critical depth upstream of the weir, yc_2= critical depth downstream of the weir, F_2= downstream Froude number, L=length of the side weir.

The flow conditions in the main channel upstream and downstream of a side weir can have a major influence on the behavior of the flow at the weir itself. There are 3 different types of the flow that happen along the weir and can best categorized in terms of the Froude number ,F, of the flow. In type 1, the flow upstream, downstream and along the length of the side weir remains subcritical at all points. The key feature to note is that the water level in the main channel increases along the weir in the downstream direction. Therefore, the head acting on the weir is greater at the downstream end than at the upstream end. As a result, the discharge intensity of the spill flow is not constant but increases in the downstream direction (Fig 1a). On the other hand, if at or near the weir, the depth of the flow in the channel is close to the critical depth, then a supercritical condition occurs and the flow depth decreases to the end of the weir. In this case, the flow upstream, downstream and along the length of side weir remain supercritical at all points (F>1). This condition can occur if the side weir is installed in a steep parent channel that is not subject to downstream regulation or control (e.g. by a gated structure or a natural constriction in the channel). As the result, the discharge intensity of the spill flow decreases towards the downstream end of the weir [Fig. 1(b)]. Finally, if there is a discontinuity in the flow, due to the downstream depth being greater than the critical depth, a hydraulic jump is expected. This condition should be avoided because the longitudinal position of the jump can be very sensitive to changes in the flow rate or roughness of the channel. Downstream of the jump, the head over the weir and the rate of outflow are significantly greater than upstream of the jump. Therefore, if the jump is not stable, the performance of the weir will be likely to be erratic and difficult to predict or control accurately. [Fig. 1(c)]. Fig. 1(a) is a typical design that usually happens in floodwater spreading system

2. Data and Material

The experiments were carried out in a trapezoidal open channel which was built at laboratory of Soil Conservation and Watershed Management Research Institute (SCWMRI) and consisted of 32 m long, 1 m base width of approach channel The longitudinal slope of the canal was set to 0.001 slope which is the usual slope in real natural rivers. The cross section of the channel was trapezoidal with 0.60 m deep. A side weir with 4 meter in length was constructed at a length of 7m from upstream inlet. The side weir was made of concrete. The discharges were measured by a system of standard sharp-crested weirs and point gauges. A rectangular sharp edge weir was installed at the beginning of the main channel which is used to adjust inlet flow. Another rectangular sharp edge weir is also used to measure lateral flow which is diverted from main channel with side weir at the end of the lateral channel. Water depth was measured using a point gauge installed at the upstream of the side weir with accuracy up to 0.1 mm (Fig. 2). The bottom of the flume material included small coarse gravel, sands which are mixed to provide the roughness coefficient of 0.02 which is a usual manning coefficient in soil bed channels (Fig 3) (Chow1959). The results were analyzed and proposed as an equation for the De-Marchi coefficient for measuring discharge in the water spreading systems. In table (2), summary of flow conditions and range of variables for discharge capacity of side weir in trapezoidal main channel is collected.

Parameters	Value
Weir length L(cm)	400
Weir height p(cm)	5
Channel slope S_0 (%)	0.001
Inlet discharge(lit/sec)	47-115
Number of runs	25

Table 1: Range of Test Variables

Fig 2: longitudinal flow profile at the side weir for discharge of 80 lit/sec

Figure 3: cross section of the trapezoidal main channel

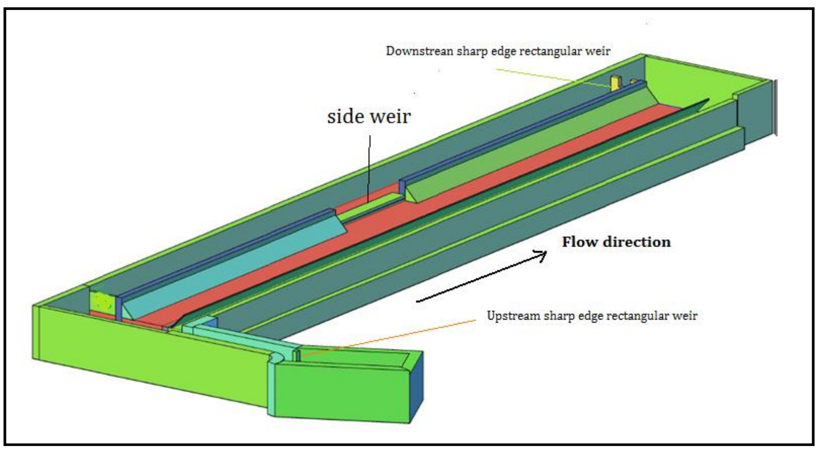

Fig 3: Laboratory Setup

3. Research Methodology

The dynamic equation of spatially varied flow for outflow over a weir is,

$$\frac{dy}{dx} = \frac{S_f - S_0 - \left(\frac{aQ}{gA^2}\right)\left(\frac{dQ}{dx}\right)}{1 - \left(a\frac{Q^2T}{gA^3}\right)} \qquad (1)$$

Where x is the horizontal distance from upstream of the weir, y is the flow depth at a distance x from upstream of the weir, dx/dy is the water surface slope, Q is the discharge of the main canal at a distance x, dx/dQ is the variation of discharge over side-weir, T is top width of the flow in the main channel and g is the acceleration due to gravity. It should be mentioned that in trapezoidal channels cross section of flow is calculated by equation (2),

$$\frac{dA}{dx} = T\frac{dy}{dx} \qquad (2)$$

Assuming that S_0-S_f = 0 (i.e., constant specific energy across the weir) and a =1, the Following DeMarchi, the discharge q over a unit length of side weir of height p is,

$$q_s = -\frac{dQ}{dx} = \frac{2}{3}\sqrt{2g}C_M(y-p)^{1.5} \qquad (3)$$

Where, q_s is the discharge for unit length of the weir, p is weir height and C_M is the De-Marchi Coefficient. At constant energy, the discharge at any section of the canal is equal to

$$dE/dx=0 \rightarrow Q = By\sqrt{2g(E-y)} \qquad (4)$$

Where; E is the energy at the specified section. For a trapezoidal main channel of base b and side slopes of 1V: mH, the pertinent geometric properties for substitution in (1), (2) and (3) are:

$$A=(b+my)y \qquad (5)$$
$$T=(b+2my) \qquad (6)$$

With the combination of the above equations, the following equation can be derived for trapezoidal channels with weir height of p and side slope of m:

$$\frac{dy}{dx} = \frac{4}{3}C_M.\left[\frac{\sqrt{(y-p)^3(E-y)}}{(3by+5my^2-2E(b+2my))}\right] \qquad (7)$$

Which upon integration between x=0 and x=L, the Length of the weir, gives:

$$\boldsymbol{L} = \frac{\mathbf{3}}{\mathbf{4}\boldsymbol{C_M}}.[\emptyset_2 - \emptyset_1] \qquad (8)$$

Where the function ϕ depends on the main channel geometry and local flow parameters and is given by:

$$\emptyset = [3m(E-5P)-6b]arcsin\sqrt{\frac{E-y}{E-p}} - \left[\frac{2P(3b-4mE+5mP)-4Eb}{E-P}\right]\sqrt{\frac{E-y}{E-p}} - -5m\sqrt{(E-y)(y-P)} \qquad (9)$$

The above equation was first introduced by DeMarchi(1934), but his equation was for rectangular channels. Cheong (1991) changed DeMarchi equation for using in trapezoidal channels for the case of zero weir height:

$$\emptyset = 4\sqrt{\frac{E}{y}-1}+\left(\frac{3mE}{b}-6\right)sin^{-1}\sqrt{1-\frac{y}{E}}-\frac{5mE}{b}\sqrt{\frac{y}{E}(1-\frac{y}{E})} \qquad (10)$$

For the case of a rectangular main channel, m=0 and (10) becomes:

$$\emptyset = 4\sqrt{\frac{E}{y}-1}-6sin^{-1}\sqrt{1-\frac{y}{E}} \qquad (11)$$

Which is In agreement with result of DeMarchi(1934) for the case of zero weir height. Base on experimental data, Cheong (1991) introduced an equation for using in a trapezoidal channel and is:

$$C_M = 0.45 - 0.22Fr_1^2 \qquad (12)$$

Using dimensional analysis, C_M can be expressed as:

$$C = f\,(F_1, L, B, w, y, S\,) \qquad (13)$$

4- Results and Analysis

As mentioned before, C_M is a function of different parameters such as F_1, p/y, L/B, S_0. Since, L/B and s_0 are constant in these experiments, these parameters are not analyzed. The first step would be to find out the effect of the most influential parameter, the upstream Froude number F_1, as suggested by most researchers. Fig. 5 shows C_M for different values of F_1. Using the experimental results, the following equation is proposed:

$$C_M = 1.121Fr - 0.387 \qquad (14)$$

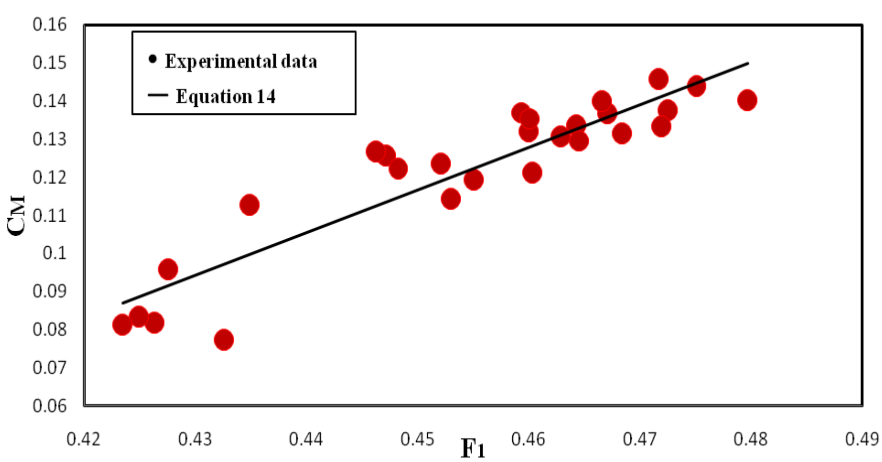

FIG 4: C_M for Different F_1 Values

It is clear that Cm is increasing with upstream Froude number. Fig. 5 shows C_M for different values of p/y_1. Using the experimental results, the following equation is proposed:

$$C_M = -0.186(p/y_1) + 0.204 \quad (15)$$

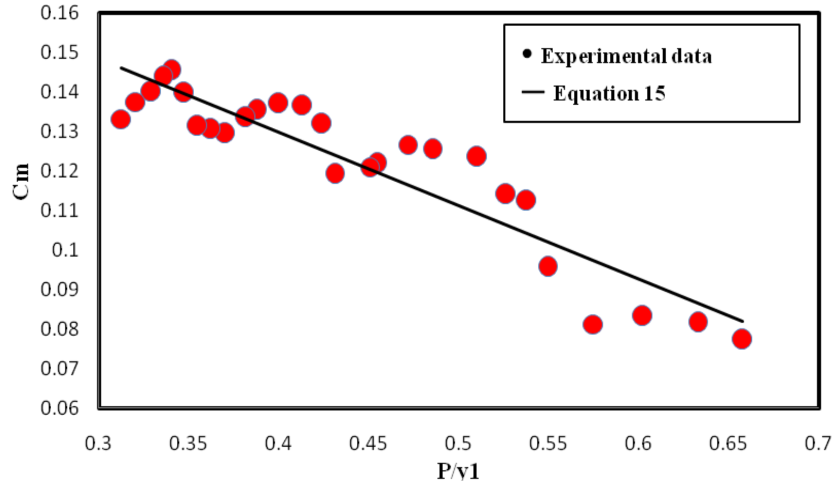

FIG 5: C_M for Different p/y_1 Values

By combining the effects of p/y1 and upstream Froude number, F_1, a new equation is presented below:

$$C_M = -0.454(p/y1)^{5.577} + 0.613(F1)^{1.963} \quad 16$$

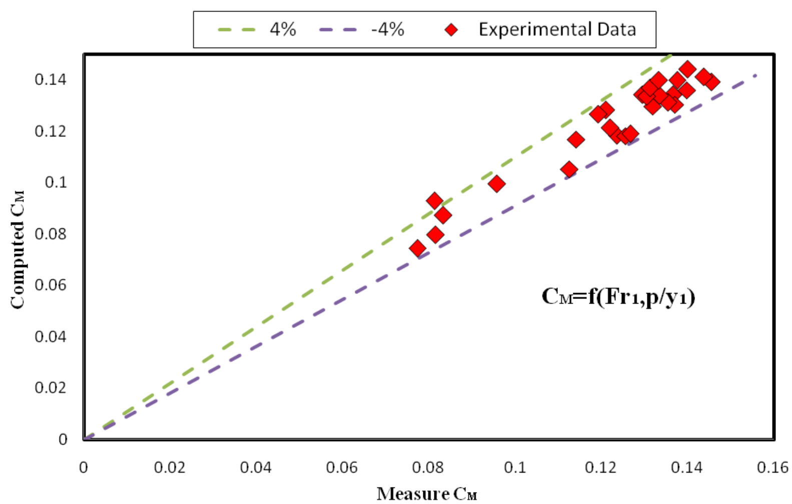

FIG 6:Measured Discharge coefficient versus Computed Discharge coefficient Using Eq. (16)

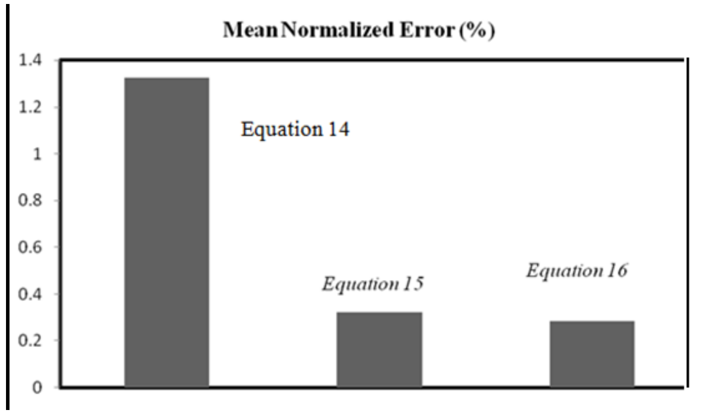

FIG 7: Normalized Error In Prediction of discharge Coefficient

Figure 7 shows the percentage difference in using equations 14, 15 and 16 respectively compared to the actual measured discharge coefficient. It is clear that the influence of p/y_1 is slightly more than upstream Froude number. On the other hand, using equation (16) instead of (15), would improve the result by about 0.05%., which is very small. Therefore equation (16) and (15) can be taken as a discharge coefficient in prediction of De-Marchi coefficient for subcritical flow for floodwater spreading systems.

5.Conclusions

Most previous researchers have investigated side weir in channels with rectangular cross sections and zero weir height, also the channels were smooth with no significant roughness coefficients However, floodwater spreading systems and most common irrigation channels have trapezoidal cross sections, weir height greater than zero and with nearly rough bed. The De-Marchi coefficient of discharge is mainly a function of F_1 and p/y_1. Therefore, a first-order polynomial equation [(16)] for the De-Marchi coefficient of discharge C_M for a side weir in a trapezoidal channel for subcritical flows in floodwater spreading systems is proposed.

Acknowledgements

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