To Calculate The Discharge Coefficient For A Broad Crested Weir With Non-Submerged Flexible Vegetation

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Abstract- Broad crested weirs are generally used as an embankment weir in flood plains for discharge measurement. Due to erosion these weirs are susceptible to failure. To avoid failure of these structures the energy of flowing water must be dissipated. In this research work, flexible vegetation with varying density were used to investigate their effect on the discharge coefficient and energy dissipation of broad crested weir (BCW). For this an experimental study was performed in the hydraulic laboratory of Civil Engineering Department UET Taxila. Flexible vegetation cover was installed over the crest of BCW, and three different densities of vegetation were used. Coefficient of discharge (C_d) and energy dissipation (ΔE) were calculated for non-submerged condition of the vegetation. From experimental work it was observed that, as the density of vegetation was changed from dense to sparse, the value of C_d increases. Lowest value of C_d was observed for 2cm c/c spacing (maximum density) and highest value of C_d was observed for 6cm c/c spacing (minimum density). It was also observed that for non-submerged condition of weir, overflow head (H) increases with increasing discharge values. As far as the energy dissipation is concerned, the ΔE decreases as the vegetation density is reduced from denser to sparse vegetation cases. Highest value of ΔE was observed in case of 2 cm c/c spacing, and lowest value of ΔE was observed in case of 6 cm c/c spacing.

Keywords- Broad crested weir, Discharge, Coefficient of Discharge, Energy dissipation.

1 Introduction

Weir is a hydraulic structure constructed across the river to raise the water level and divert a portion of the river flow for irrigation, power generation, water supply schemes and measure discharge [1].These are normally overflow structures build as a rigid wall of concrete, brick masonry, stone masonry and compacted earth. Sometimes weirs are provided with gates. The gates regulate only a small portion of water. The major portion of water is regulated through crest. Normally weir is provided at right angle to the axis of the river, but oblique weir may also be provided. There are broad crested earthen weirs, with sloping ramps on upstream as well as on downstream sides. Such a weir is also used in flood plains to measure discharge. Broad crested embankment weir has higher discharge capacity as compare to broad crested weir with vertical faces. Embankment weir has a normal slope of 1V: 2H to provide proper stability of slope and control the seepage through embankment weir [2]. The increase in the upstream slope of weir also increases the head loss through the weir and vice-versa. Also it has been concluded that head loss decreases as the downstream water depth increase [3]
Broad crested embankments weirs are overflow hydraulic structures. Due to overflow condition theses are more susceptible to failure due to continuous erosion of the crest. Now a day's environmental friendly materials (such as rip-rap, stone pitching and gabions) are used to increase the surface roughness and provide maximum resistance to the flow. In embankment weir discharge is reduced by increasing the roughness of surface. The roughness of the crest had its effects

on velocity distributions and shear stress [4]. The effect of weir height is directly proportional to discharge coefficient, while the effect of surface roughness is inversely proportional to discharge coefficient [5].

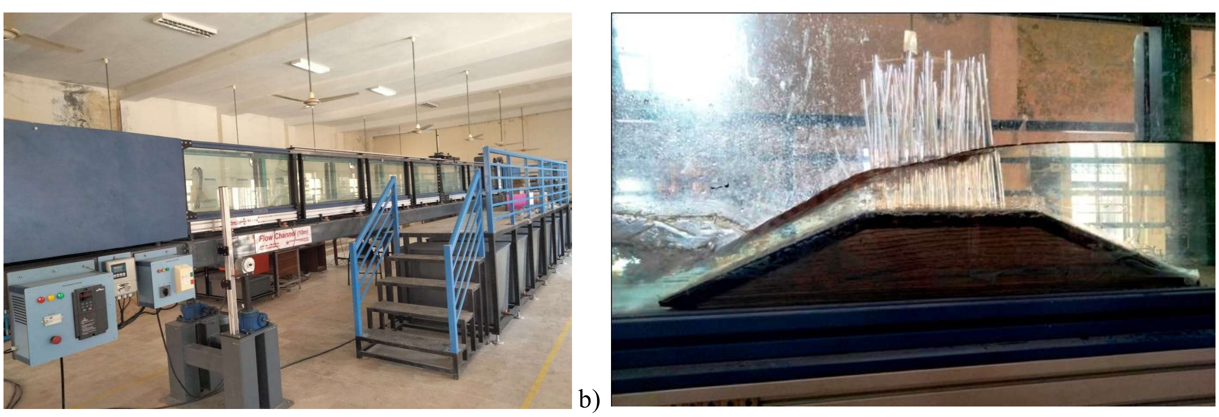
Plants and vegetation also play a vital role in reducing the effect of high velocity of the flow. Plants are provided in flood plains to minimize the effects of flood and reduce transport of sediments. To design safe embankments, the vegetated weirs play an important role in raising the flood water level. It has also been investigated that vegetation cover over the crest of embankment causes much loss in the head of flood water [6]. Vegetation occurs naturally on embankment and creates maximum turbulent behavior for the flow. Due to turbulence behavior in the zone of vegetation, energy is dissipated. As compare to smooth embankment weirs, vegetative embankment weirs offers greater turbulence and resistance to flowing water. It is also investigated that upstream water head is directly proportional to the roughness of the embankment weir, because of the availability of vegetation over it [7]. The flow resistance varies with stem diameter, vegetation density and elastic properties of vegetation [8]. Hydraulic performance of semi circular increases by 45% with the increase of particle size of roughness material [9]. As compare to other slopes, slope of 1:3 for downstream ramp was most appropriate for discharge coefficient [10].

In the present research, the impact of flexible vegetation cover with varying density on the discharge coefficient of a broad crested weir has been investigated. The energy loss has also been investigated. The results have been shown in the graphs.

2 Experimental Procedure

All the experimental work was executed in the hydraulic laboratory of civil engineering department, University of Engineering and Technology Taxila. A glass walled open channel with rectangular x-section was used for all the experiments (Fig. 2.1a). The channel is fitted with six tanks below it which supply water to the channel through a pump. These tanks were filled manually using a water pipe.

A model of BCW was prepared using plywood and it was installed in the channel (Fig. 2.1b). The weir model was trapezoidal in shape. Model had an upstream ramp, a crest and a downstream ramp. A slope of 1V: 2H was provided both for upstream & downstream ramps. The crest of the weir was 25cm in length, whereas the crest height & width were 11cm and 31cm respectively. Circular holes of diameter 0.9cm were drilled at a distance of 2cm center to center over the crest of the weir in a square pattern



a) b)

Figure 2.1: a. Rectangular glass channel, and b. Weir model inside the channel

Weir model were installed 4m downstream from the inlet of the open channel. Different pattern of flexible vegetation were fixed at the crest of weir model with varying density. A movable scale was fixed over the channel, which was used to measure the depth of water at two measuring stations.

Vegetation used over the crest of the weir was flexible. Flexible sticks made of silicon were used as flexible vegetation over the crest of the weir. The flexible sticks were 22.5cm long and had a diameter of 0.8cm.These sticks were transparent and could bend with the flow of water.

3 Research Methodology

Three cases of flexible vegetation cover over the crest of the weir were studied in this research work. This has been shown in Fig. 3.1.

- Case-1: Flexible vegetation with 2cm c/c spacing (max. density)
- Case-2: Flexible vegetation with 4cm c/c spacing (intermediate density)
- Case-3: Flexible vegetation with 6cm c/c spacing (min. density)

For each case of vegetation cover, four different flow rates (Q) were used. These flow rates were 0.21ft^3/s, 0.36 ft^3/s, 0.51 ft^3/s and 0.59 ft^3/s..

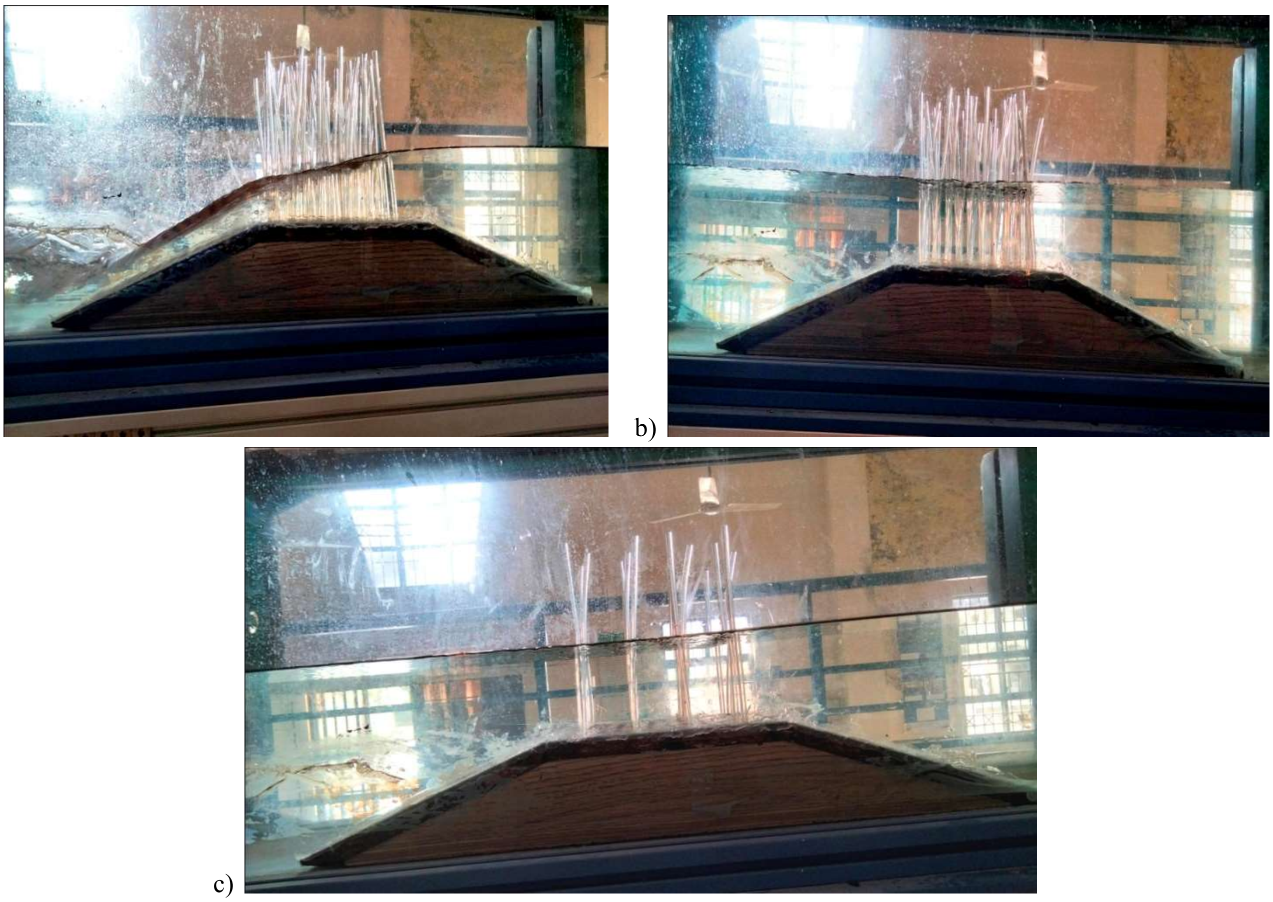


Figure 3.1: Flexible vegetation with a. 2cm c/c spacing, b. 4cm c/c spacing, c. 6cm c/c spacing

3.1 Calculation for C_d and ΔE

Discharge passing through broad crested trapezoidal weir was calculated using Eq.1 [11]

$$Q = C_d * B * \sqrt{g\left(\frac{2}{3} * H\right)^3} \qquad (1)$$

Where;
Q = Discharge (ft^3/s)
B = width of weir (ft)
H = Overflow head over the crest of the weir (ft)
C_d = Co-efficient of Discharge

Coefficient of discharge can be found using Eq.2

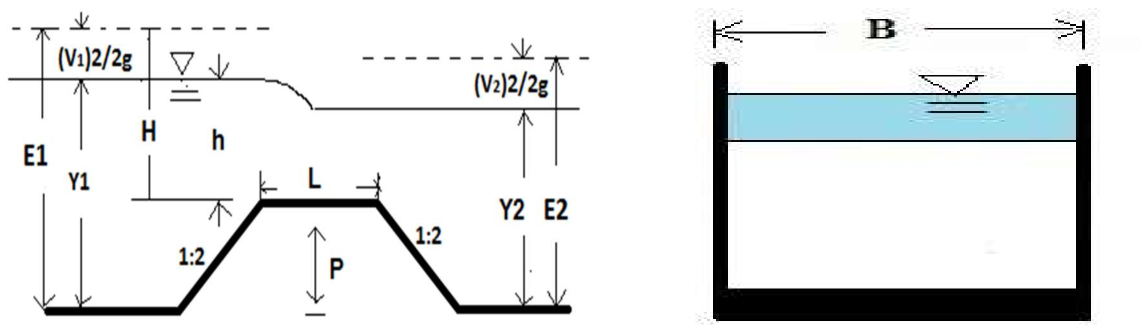
$$C_d = \frac{Q_{act}}{Q_{theo}} \quad (2)$$

Energy dissipation (ΔE) through the weir was calculated using following general equation

$$\Delta E(\%) = \frac{E_1 - E_2}{E_1} * 100 \quad (3)$$

$$E_1 = Y_1 + \frac{{V_1}^2}{2g} \quad (4)$$

$$E_2 = Y_2 + \frac{{V_2}^2}{2g} \quad (5)$$



a) b)

Figure 3.2: a. Profile of weir, and b. suppressed rectangular sharp crested weir

3.2 Calculation of actual discharge in channel

The actual discharge (Q_{act}) in the channel was calculated using sharp crested rectangular suppressed weir (Fig.3.2b). It was installed at a distance of 4m d/s of the inlet. Discharge was calculated using the following equation for suppressed rectangular sharp crested weir [12].

$$Q = 3.33 * B * H^{3/2} \quad (6)$$

Where;

B = width of weir (ft) (here B=3.10 ft)
H = depth of water over the crest (ft)
Q = discharge (ft^3/s)

4 Results & discussions

By measuring the flow depths at u/s and d/s of the broad crested weir, the coefficient of discharge (C_d) and energy dissipation (ΔE %) were calculated for all the three vegetation cases against various discharge values. Results of all the three densities were compared and following graphs were plotted.

Figure 4.1(a) shows the variation of C_d values for different densities of vegetation. As the density of vegetation change from max. to min., the values of C_d increases. Hence it is concluded that C_d is inversely proportional to the density of vegetation cover. Vegetation provides resistance to the flow by increasing Head over the crest. So discharge is reduced.

C_d has lowest values for 2cm spacing (max. density) of vegetation at the corresponding depths, and highest values for 6cm spacing (min. density).

Figure 4.1(b) shows that for non-submerged condition of weir, overflow head (H) increases with increasing discharge (Q) values. From Equation of flow it is obvious that Flow (Q) is directly proportional to Head (H), so the results are justified.

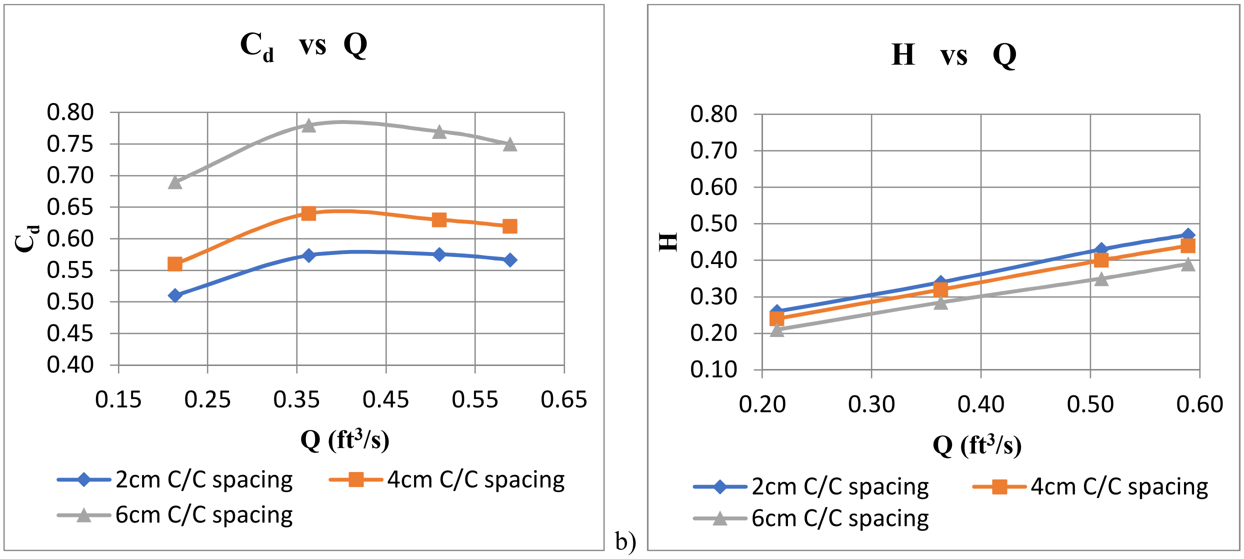


Figure 4.1: a. C_d vs. Q results for flexible vegetation with different densities, b. Over flow head (H) vs. Q results for different densities of flexible vegetation.

Following graph show the relationship between energy dissipation and downstream water depth (Y_2). Figure 4.2 shows the values of ΔE for different densities of vegetation. As the density of vegetation change from dense to sparse, the values of ΔE decrease. Due to Vegetation U/s head is increases and the velocity of the flow decreases. Thus creating a deep pool of water for maximum energy dissipation. Energy dissipation is highest for 2cm c/c spacing (max. density) and lowest for 6cm c/c spacing (min. density).

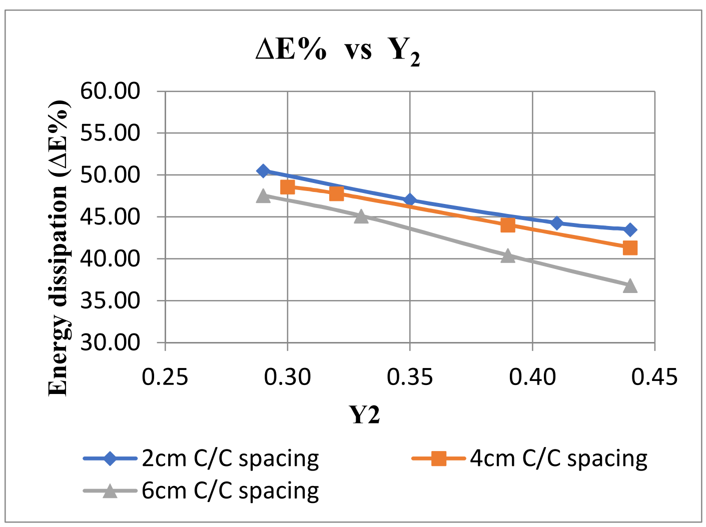


Figure 4.2: Effect of density variation on ΔE for flexible vegetation

This research may be applied practically in flood plain for the safety of Embankment weirs against failure. Flexible vegetation over the crest of weir structure increases surface roughness and energy dissipation. So the risk of Crest Erosion is minimised. Apart from vegetation we may also use gabions, stone-pitching and rip-rap over crest to increase surface roughness.

5 Conclusion

Following conclusions could be drawn from this research work:

1. C_d values were maximum for 6cm c/c spacing (min. density) and was minimum for 2cm c/c spacing (max. density).
2. It was also observed that for non-submerged flow condition, the overflow head (H) increases with increasing discharge.
3. Maximum value of energy dissipation was observed for 2cm c/c spacing (max. density) and was minimum for 6cm c/c spacing (min. density).

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