Experimental Investigation for Discharge Coefficient of an Embankment Weir Using Smooth and Vegetated Embankments

Hafiz Muhammad Aamir[1], Usman Ghani[1], Muhammad Kaleem Ullah[2], Ghufran Ahmed Pasha[1]

[1] *Department of Civil Engineering, University of Engineering and Technology, Taxila, Pakistan*
[2] *Department of Civil Engineering, University of Lahore, Pakistan*

Abstract: **Weirs, commonly used as flow control structures in water resources engineering, are also used for discharge measurement. In this study, experiments were conducted at Hydraulic Engineering laboratory of Civil Engineering Department UET Taxila by using smooth and vegetated embankment weirs. In order to determine the variation of discharge coefficients on a broad crested embankment weir, smooth and vegetated conditions were used for different flow intensities ranging from 8-50 liter/second. A broad crested embankment weir having crest length 90 cm, width 96 cm, height 30 cm and side slopes of 1V:2H, was installed in the laboratory channel. The increase in resistance yields the decrease in discharge coefficient. In this study, to achieve different types of vegetation, a grass type vegetation having grass height of 40 mm and rigid vegetation such as stem type with height 8 cm and diameter 2 cm were used on the embankment weir. The results of vegetated weir were compared with that of the smooth embankment weir. Based upon the calculations and observations that carried by experimental setup, we recorded that the vegetated embankment weir creates higher resistance and higher turbulence behavior for the flow as compared to that obtained from smooth embankment weir.**

Keywords: **Discharge coefficient, Embankment weir, Flow Efficiency, Vegetation**

I. INTRODUCTION

In hydraulics engineering, weirs are commonly used to increase the stream water level for enhancing the irrigation and water storage capacity and is used for navigational purposes [1]. Embankment weirs are normally used in hydrotechnical engineering as discharge measuring devices, as lateral weirs on flood levees etc. [2]. Weirs of various shapes are installed for the measurement of discharges [3]. For highways and for hydroelectric schemes broad-crested weirs and embankment weirs are common engineering structures in irrigation systems [4]. A weir is called broad crested weir when the pressure distribution is hydrostatic and when the streamlines of flow are parallel to the crest [5]. Depending upon the requirements, broad-crested weirs can have a lot of cross sections in the control sections and in irrigation structures [6]. For the investigation of broad crested weir with upstream and/or downstream slopes many experimental studies have been carried out. Many researchers have tried to formulate head-discharge relations depending upon their measurements and with the literature [7]. The conditions on the inclining horizontal sides of such a weir vary from the conditions on the vertical sides of the rectangular weir [8]. Numerical and experimental studies of flow over trapezoidal profile weirs have a number of applications especially in the analyses of flow over common types of civil engineering structures. The significant nature of flow over such types of weirs, especially in the vicinity of flow transition from subcritical to supercritical state, is a strong departure from the hydrostatic distribution of pressure, caused by the curvatures of the streamlines [9]. From geotechnical contemplation, the embankment slope is ordinarily used 1V: 2H because of bank stability and drainage control. Sloping banks have a higher discharge capacity than the standard broad-crested weir with vertical faces. For a flow over a smooth embankment weir, the discharge coefficient shows the flow capacity of the flow [10]. Small scale structures such as ripples and dunes are often offered resistance to the flow in many channels [11]. Dikes, trees, roads, bushes, ditches and grass offered more resistance to the flow in the flood plain which ultimately give rise to the flood level. High resistance is there against flow due to the amalgamation of elevation and vegetation which give rise to high flood level inside flow channel [12]. Vegetations such as rigid and flexible vegetation either emergent or submerged provide sufficient resistance to the flow of sediments in the channels and on the overtopping structures in the flood plains [13]. Experimental studies were performed on flexible vegetation and rigid vegetation and results were compared with one another [14]. In irrigation channels, drainage channel on highways, and on the river embankment revetments grass vegetation is beneficial to mitigate the erosion by flow [15].

Many experiments were already performed on embankment type weir. This paper covers the case: grass vegetation i.e. flexible vegetation with the grass height 40 mm and rigid vegetation such as stem type rigid rod with the height of 8 cm and 2 cm diameter of each rigid vegetation. The determined discharge coefficients were compared with the case of smooth embankment weir.

II. MATERIALS & METHODS

A. Methodology

Experimental study was carried out at the Hydraulics Laboratory, Civil Engineering Department, University of Engineering and Technology, Taxila. An open channel of rectangular dimensions, that is, 96 cm wide, 75 cm deep and 20 m long with glass side walls and concrete bottom was used for experimental setup. Flow was supplied to the channel from under-ground tank through pump. The discharge was measured by using compound rectangular trapezoidal sharp crested weir provided at the end of channel. The measurement of water level was carried out by point gauges installed within the channel. The flow range during experimentation was 8-50 liter/second for each case. In laboratory, embankment weir with crest length 90 cm, crest height 30 cm, crest width 96 cm and with upstream and downstream sides slope 1V:2H was installed with varying vegetation on the crest as well as upstream and downstream ramps of the weir. The weir was made up of smooth ply wood; installed at 5 m downstream from the channel entrance. Three different cases i.e. smooth embankment weir, grass type vegetation with grass height 40 mm on embankment weir and rigid vegetation such as stem type rigid rod of 8 cm height and 2 cm diameter having c/c distance of 4 cm placed at the center line of crest of the embankment weir were used during the experimentation to determine the discharge coefficients.

Fig 1: Smooth Embankment Weir

Fig. 2: Embankment Weir with Grass Vegetation

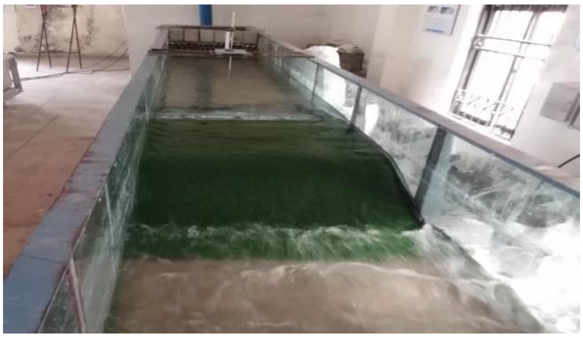

Fig. 3: Embankment Weir with Grass Type Vegetation During Flow

Fig. 4: Embankment Weir with Rigid Vegetation at the Center of Crest of the Weir

B. Discharge Measurement

A compound rectangular-trapezoidal sharp crested weir, designed as per ASCE specifications, is installed at the end of the rectangular channel to measure the total discharge of the channel.

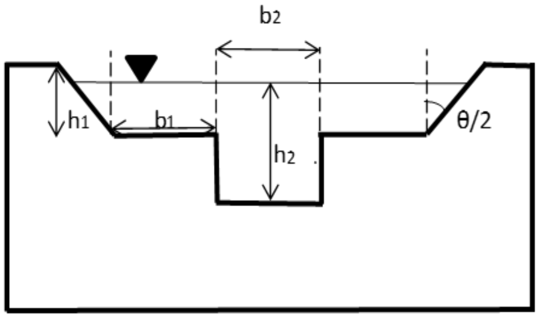

Fig. 5: Compound weir at the end of channel to measure the discharge

Following equation was used for the measurement of total discharge. (Henderson 1966).

$$Q = \frac{2}{3} C_{rd2} \sqrt{2g} b_2 h_2^{\frac{3}{2}} + \frac{2}{3} C_{rd1} \sqrt{2g} (2b_1) h_1^{\frac{3}{2}} + \frac{8}{15} C_{td} \sqrt{2g} \tan\left(\frac{\theta}{2}\right) h_{1e}^{\frac{5}{2}} \quad (1)$$

b = length of weir
C_{rd}= coefficient of discharge of sharp-crested rectangular weir
C_{td}= coefficient of discharge of sharp-crested triangular weir
g = gravitational acceleration
h = depth of water on the crest of weir
h_e = effective head
θ = angle of notch of the weir

$$C_{rd} = \frac{0.611+2.23(\frac{B}{b}-1)^{0.7}}{1+3.8(\frac{B}{b}-1)^{0.7}} + \frac{0.075+0.011(\frac{B}{b}-1)^{1.46}}{1+4.8(\frac{B}{b}-1)^{1.46}} \frac{h}{p} \quad (2)$$

The values of C_{rd} depend upon the width of channel B, length of weir b, depth of water h and height of the weir P. (French 1986)

$$h_e = h + K_h \quad (3)$$

K_h = Correction head. The value of K_h is in mm. This factor measures the viscous forces and effects of surface tension.

$$K_h = 3.9058 - 3.8558\theta + 1.1940\theta^2 \quad (4)$$

$$C_{td} = 0.6085 - 0.0525\theta + 0.02135\theta^2 \quad (5)$$

θ = angle of notch of the weir

Discharges can be calculated by using (1)

C. Experimental work Calculations

To determine the discharge coefficient for each case mentioned above, first we measured total discharge with the help of (1). Then by measuring upstream head 'H' with the help of point gauge installed in the channel we calculated discharge coefficient by using (6).

$$Q = C_d\, B \sqrt{g\left(\frac{2}{3}H\right)^3} \quad (6)$$

Q = Total discharge through the channel

H = Upstream head of the weir

C_d = Coefficient of discharge

III. RESULTS

Following graphs have been plotted after experimentation for each case, by calculating discharge coefficient and upstream head of the embankment weir for different values of discharges. Graphs demonstrate the relationship between discharge coefficient (Cd) and upstream head over length of crest of weir (H/L). Discharge coefficient (Cd) and upstream head over length of crest (H/L) both are unitless quantities.

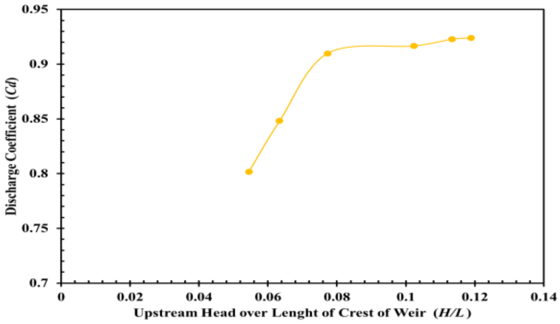

Fig. 6: Relation between Discharge Coefficient (Cd) and (H/L) using smooth embankment weir

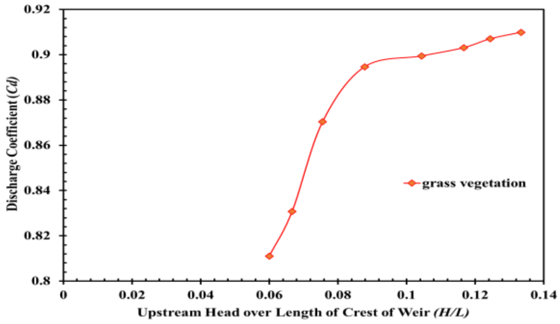

Fig. 7: Relation between Discharge Coefficient (Cd) and (H/L) using grassy vegetation on embankment weir

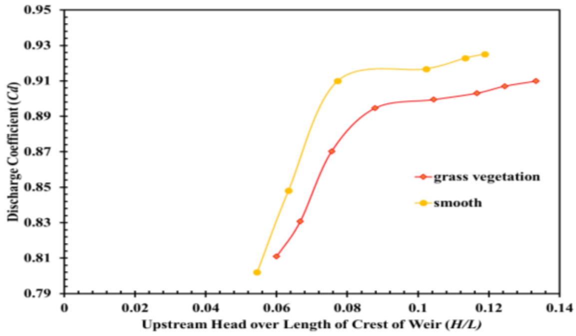

Fig. 8: Comparison between discharge coefficient (Cd) and (H/L) using smooth weir and grassy vegetation on embankment weir

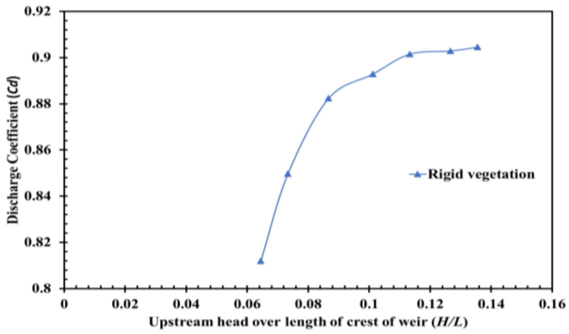

Fig. 9: Relation between discharge coefficient (Cd) and (H/L) using rigid vegetation on embankment weir

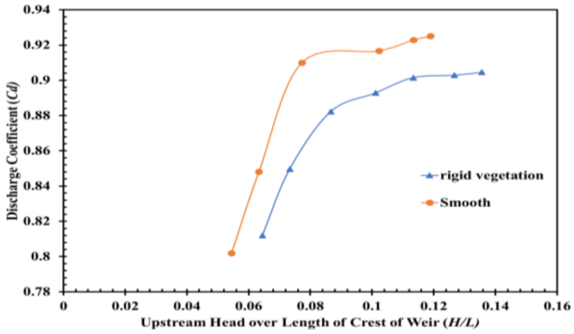

Fig. 10: Comparison between discharge coefficient (Cd) and (H/L) using smooth weir and rigid vegetation on embankment weir

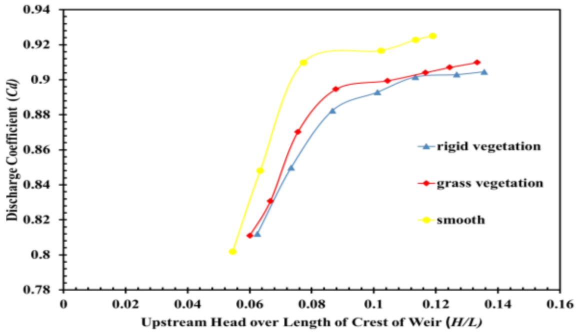

Fig. 11: Comparison between discharge coefficient (Cd) and (H/L) using smooth weir and different vegetations on embankment weir

IV. CONCLUSION

By experimentation, we observed that as the value of roughness increases, the value of discharge coefficient decreases. In case of roughness provided by grass vegetation and rigid vegetation, the values of discharge coefficient are less as compared to that values obtained by using smooth embankment weir. We also noted that head on upstream increases with the increase of roughness on the embankment type weir due to the presence of different types of vegetations. So, due to the presence of vegetation on the embankment type weir, the flow efficiency is affected and it becomes low as compared to that in the case of smooth or un-vegetated embankment weir.

V. RECOMMENDATIONS

The erosion phenomenon becomes a tremendous problem for flood control structures such as embankment type structures during floods. Grass type vegetation is very useful for the protection of erosion on such structures. Other types of roughness elements such as gravels can also be used for the purpose of flood control on the flood control structures. For the enhancement of surface roughness of different flood control structures different roughness elements other than the grass vegetations and gravels can also be utilized.

REFERENCES

[1] S. Felder and N. Islam, "Hydraulic Performance of an Embankment Weir with Rough Crest," J. Hydraul. Eng., vol. 143, no. 3, pp. 1–11, 2017.
[2] J. P. A. Ř. Ílková, J. Ř. Íha, and Z. Ě. K. Zachoval, "THE INFLUENCE OF ROUGHNESS ON THE DISCHARGE COEFFICIENT OF A BROAD-CRESTED WEIR," J. Hydrol. Hydromechanics, vol. 60, no. 2, pp. 101–114, 2012.
[3] O. Castro-orgaz and H. Chanson, "Depth-Averaged Specific Energy in Open-Channel Flow and Analytical Solution for Critical Irrotational Flow over Weirs," J. Irrig. Drain. Eng., vol. 140, no. 1, pp. 1–8, 2014.
[4] J. E. Sargison and A. Percy, "Hydraulics of Broad-Crested Weirs with Varying Side Slopes," J. Irrig. Drain. Eng., vol. 135, no. 1, pp. 115–118, 2009.
[5] S. Felder and H. Chanson, "Free-Surface Profiles , Velocity and Pressure Distributions on a Broad-Crested Weir : A Physical Study," J. Irrig. Drain. Eng., vol. 138, no. 12, pp. 1068–1074, 2012.
[6] Z. Defne, "Broad-Crested Weirs with Rectangular Compound Cross Sections," J. Irrig. Drain. Eng., vol. 132, no. 3, pp. 272–280, 2006.
[7] A. H. Azimi, N. Rajaratnam, F. Asce, D. Z. Zhu, and M. Asce, "Discharge Characteristics of Weirs of Finite Crest Length with Upstream and Downstream Ramps," J. Irrig. Drain. Eng., vol. 139, no. 1, pp. 75–83, 2013.
[8] V. I. Bukreev, V. V Degtyarev, and A. V Chebotnikov, "Discharge and energy-loss coefficients in flow through a breach in a trapezoidal dam," J. Appl. Mech. Tech. Phys., vol. 49, no. 1, pp. 53–57, 2008.
[9] J. D. Zerihun, Y.T. and Fenton, "A Boussinesq-type model for flow over trapezoidal profile weirs," J. Hydraul. Res., vol. 45, no. 4, pp. 519–528, 2007.
[10] B. H. M. Fritzi and W. H. Hager, "HYDRAULICS OF EMBANKMENT WEIRS," J. Hydraul. Eng., vol. 124, no. 9, pp. 963–971, 1998.
[11] S. Ali and W. S. J. Uijttewaal, "Flow Resistance of Vegetated Weir-like Obstacles during High Water Stages," J. Hydraul. Eng., vol. 139, no. 3, pp. 325–330, 2012.
[12] S. Ali and W. S. J. Uijttewaal, "Flow resistance of vegetated oblique weir-like obstacles during high water stages," Hydrol. Earth Syst. Sci., vol. 18, no. 1, pp. 1–14, 2014.
[13] W. Wu and Z. He, "Effects of vegetation on flow conveyance and sediment transport capacity," Int. J. Sediment Res., vol. 24, no. 3, pp. 247–259, 2010.
[14] K. Panigrahi and K. K. Khatua, "Prediction of Velocity Distribution in Straight Channel with Rigid Vegetation," Aquat. Procedia, vol. 4, no. 1, pp. 819–825, 2015.
[15] C. A. M. E. Wilson, "Flow resistance models for flexible submerged vegetation," J. Hydrol., vol. 42, no. 3–4, pp. 213–222, 2007.