TECHNICAL NOTE

TWIN PLATE WEIR: A FLOW MEASURING DEVICE

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Abstract For efficient use of water, accurate measurement of flow in (field/laboratory) channels is required for many water resource projects. The present work is aimed to study the flow characteristics of a twin plate weir (two sharp-crested plates are placed one behind the other at some distance) under free and submerged flow conditions. Experiments are performed with four spacing of the twin plate weir ranging from 10 cm to 40 cm under free and submerged flow conditions. It was observed that the coefficient of discharge (Cd) is a function of head over the crest (H_1) and height of the plate of the weir (P) in free flow condition. The critical submergence (H_2/H_1) increases as the discharge increases, for a particular spacing of the twin plate weir (L). The critical submergence also increases with the increase in the spacing of the weir plates for any discharge. When some material fills the space between the two plates, the Cd increases as the percentage of filling increase. The device may prove quite useful when siltation occurs between the twin plate weirs. The device could be utilized in laboratory/industry channels for the discharge measurement.

Keywords Channels, Coefficient of Discharge, Weirs, Discharge Measurement

چکیده برای بهره مندی بهینه از آب در ارزیابی منابع آبی، اندازه گیری دقیق جریان در کانال ها چه در صحرا و یا آزمایشگاه مورد نیاز است. کار حاضر مربوط به مطالعه ویژگی های جریان آب در یک آبریز با دو مجرای صفحه ای است که دو صفحه آن با لبه تیز بالایی، پشت سر هم بطور موازی قرار گرفته که تحت جریان آزاد و مغروق می‌باشند. آزمایش های مربوط به چهار حالت برای فاصله های بین دو صفحه بین ۱۰ تا ۴۰ سانتی متر تحت جریان آزاد و مغروق انجام شده است. مشاهدات حاکی از تغییر ضریب عبور جریان (Cd) به صورت تابعی از فشار آب روی لبه بالائی صفحه (H_1) و ارتفاع صفحه در آبریز (P) در جریان آزاد است. حالت غرق شدگی بحرانی صفحات با شاخص (H_2/H_1) با افزایش دبی خروجی، برای یک فاصله خاص دو صفحه افزایش می‌یابد. همچنین این حالت غرق شدگی بحرانی نیز در هر دبی با افزایش فاصله دو صفحه افزایش می‌یابد. در صورتی که فاصله بین دو صفحه با یک ماده پر شود، ضریب Cd با افزایش درصد پر شدگی این ماده افزایش می‌یابد. برای اندازه گیری رسوب گذاری لای بین دو صفحه، از این وسیله می‌توان استفاده کرد. دبی عبور جریان در کانال های مشابه چه در آزمایشگاه و چه در صنعت با این وسیله قابل تعیین است.

1. INTRODUCTION

Effective use of water for crop irrigation requires the measurement of flow rates and volumes which is expressed quantitatively. Metering makes the farmers conscious of the proper use of water and prevents overuse and water wastage. Measurement of flow rates in an open channel is difficult because of non-uniform channel dimensions and variations in velocities across the channel. Weirs allow water to be routed through a structure of known dimensions, permitting flow rates to be measured as a function of depth of flow through the structure. Thus, one of the simplest and most accurate methods of measuring water flow in open channels is by the use of weirs. The sharp-crested weirs are normally used in the measurement of irrigation water. Weirs provide a simple and accurate method of measuring flow rates in an open channel.

It is a structure built across a river or streams in order to raise water level on the upstream side and to allow excess water to flow over its entire length. Weirs are of different types, depending on the shape of the opening, the crest and the effect of side walls on nappe and also discharge conditions. Sharp crested weirs are used in industries, laboratories and irrigation practices. The role of thin plate devices is restricted to situations, where maintenance is good and there is a little risk of damage or deterioration, particularly when the flow to be measured contains debris of sediments. Each type of weir is suitable only for a specific condition. In higher flow, a wider crest weir (Broad crested weir) is required if afflux is not excessive, while for a smaller flow, a narrow or sharp crested weir is required. These two criteria are never met. It is necessary that flow characteristics of a weir such as coefficient of discharge, critical submergence ratio and etc are known before being used (Lakshmana Rao, et al [1], Bos, et al [2], Ackers, et al [3], Subramanya, et al [4].The literature review indicates that Wu, et al [5] have studied submerged flow over rectangular sharp crested weirs and suggested a diagram to predict a flow regime namely impinging jet and surface flow. The discharge coefficient for flat topped and sharp crested weir has been studied recently by Jhonson, et al [6]. Baylar, et al [7] investigated the sharp-crested weirs having different cross-sectional geometry and their effect on the air entrainment rate. The 30˚ triangular sharp-crested weir with two V-notches was found to have higher values of air entrainment rate. Ismail et al [8] have proposed a rectangular slit weir which is designed for measurement of small (< 0.005 m^3/s) discharges. The discharge coefficient is determined experimentally using the measured discharges and the corresponding heads over the weir. The relationship between the discharge coefficient and all relevant dimensionless parameters is investigated. It is concluded that the discharge coefficient can be represented solely as a function of Reynolds number. A rectangular sharp-crested weir, which can be placed obliquely in front of the flow, increasing the effective weir length and hence, increasing the discharge for the same water head with the same channel width. Since with oblique weirs extends the effective length, the efficiency of the weir is also increased. This kind of weir is aerated automatically and therefore does not need aeration. Finally a single formula for discharge coefficient, relating to all tested oblique angles, in a free flow situation has been introduced, and correction coefficients for submerged flow have been suggested.

Ismail, et al [9] have designed slit weirs to measure small flow discharges in open channels. Experimental data available in the literature are added, to study the effect of the slit width. An explicit relation for the discharge coefficient is obtained by a conventional Reynolds number definition. The discharge coefficient is modified to increase the working range of slit weirs for small values of head to slit-width ratios. A review of the literature indicates that, as per authors' knowledge no one attempted to study twin plate weir for open channels in irrigation fields.

The sharp and broad crested weirs can not be employed at higher submergence. Moreover, flow with sediments can not be measured accurately by the above weirs. An attempt has been made in the present study by performing experiments on two plate weirs in the laboratory called twin weir. This experimental study is taken up with an aim to make use of its advantages and remove the drawbacks of sharp and broad crested weirs.

2. FLOW CONDITIONS

Flow characteristic of twin plates weir under free and submerged flow conditions are studied. In free flow water, level is far below the crest and when tail water is above the crest it is called submerged flow. The ratio of downstream water level to upstream is called as H_2/H_1 submergence ratio. The submergence causes reduction in the flow. The minimum value of submergence ratio when discharge deviates 1.5 % by the free flow e.g. it is termed as modular limit or critical submergence. In broad crested weirs the surface tension and the viscosity effects are insignificant and neglected. As the value of $Re^{0.2} W_1^{0.6}$ (where Re is the Reynolds number and W is Weber number) is more than 900 in the present study, so there is no need of considering surface tension and viscosity effects on the coefficient of discharge. (Ranga Raju, et al [10]).

3. EXPERIMENTAL DETAILS

The experiments were carried out in Hydraulics laboratory of Civil Engineering Department of National Institute of Technology, Kurukshetra, India, in a rectangular flume 56.5 cm wide and 60 cm deep which was almost horizontal (Figure 1). A 15 HP centrifugal pump started to pump water from the sump well to the overhead tank. The channel received water from 12.5 cm diameter cast iron pipe. An orifice meter was provided in the inlet pipe to measure the rate of flow, which was pre calibrated. Two steel plates of size 40 cm x 60 cm were cut form a big plate 3 mm thick and both plates were beveled at an angle of 45° upstream edge. The spacing of two plates was chosen per broad crested range. The spacing or width of weir is selected in such a way that it satisfies the range of broad crested weir ($0.1 < H_1/L < 0.35$), where H_1 head over the weir and L is the spacing between the plates. For a spacing of 10cm, the twin plate weir was filled with sand for 25 %, 50 %, 75 % and 100 % of height of the weir and variation of Cd was studied. The experimental scheme is mentioned in Table 1. The ranges of all tested variables are given in Table 2.

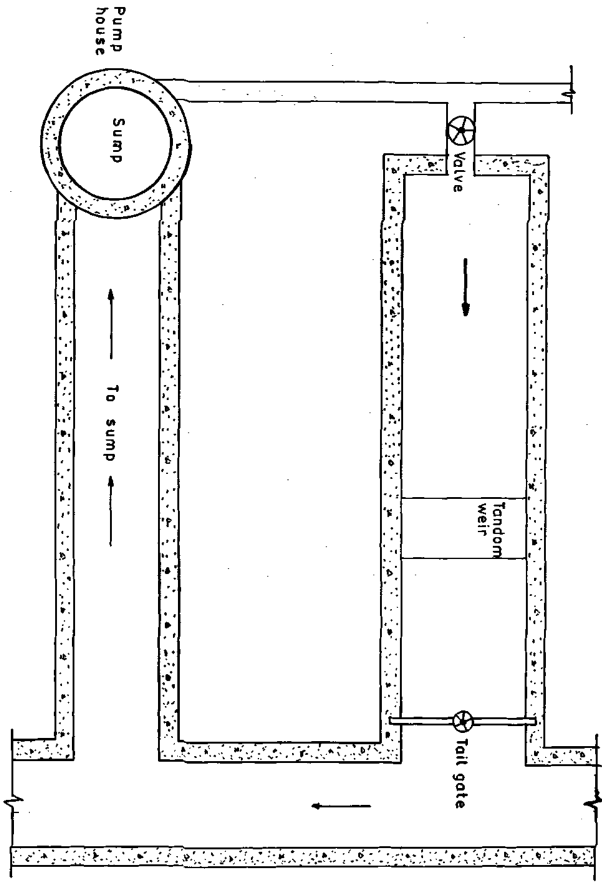

Figure 1. Layout plan of experimental set-up.

4. EXPERIMENTAL PROCEDURE

A sharp crested weir with suppressed end was embedded in the walls on either side of the concrete channel. A stilling well type arrangement was provided to avoid disturbances caused by surface ripples, in measuring water heads. A glass cylinder was placed at 40 cm form the upstream edge of weir and in which, water got collected by siphon action through a rubber tube at atmospheric condition. On downstream of the weir two rubber tubes were provided for proper ventilation of weir plates. The water depths of the upstream and also downstream of the weir were noted by a pointer gauge. Various sets of discharges were taken and in each case the upstream head for free and also upstream/downstream heads for submerged flow were noted as shown in Figure 2a,b.

5. ANALYSIS OF RESULTS

The experimental data collected from the present study is analyzed in the following paragraphs for free and submerged flow conditions (Dilip, et al [11]).

5.1. Effect of Twin Plate Spacing on Cd

Figure 3 shows a graph between Cd and H_1/P_1 for different spacing of plates (L). It can be observed that as the value of H_1/P_1 increases, the value of Cd gradually increases for larger spacing of plates i.e. L = 20.5 cm, 29.7 cm, 40 cm. The increase is much more for spacing L = 10 cm. Although the C values for sharp crested weir is large, but it is nearly constant for any value of H_1/P_1.

5.2. Effect of % of Filling on Cd The space between the plates (L = 10 cm), is filled with sand

TABLE 1. Scheme of Experimentation.

S No	Upstream Head Range Above the Crest (H_1)	Spacing Between Two Plates (L)	% of Filling by Sand
1	4 cm to 14 cm	10 cm	25, 50, 75, 100
2	5 cm to 14 cm	20.5 cm	Nil
3	5 cm to 14 cm	29.5 cm	Nil
4	4 cm to 14 cm	40 cm	Nil

TABLE 2. Range of Variables Tested.

S No	Spacing Between Plates L (cm)	H1/L Minimum Value	H1/L Maximum Value	Q Min Value ($10^{-3} m^3/s.$)	Q Max Value ($10^{-3} m^3/s.$)
1	10	0.49	1.30	8.83	30.9
2	20.5	0.215	0.797	7.26	28.8
3	29.5	0.180	0.492	9.42	36.5
4	40	0.133	0.368	9.43	36.0
5	10	0.110	0.408	8.83	30.9
6	20.5	0.133	0.363	7.26	28.8
7	29.5	0.133	0.368	9.42	36.5
8	40	0.124	0.336	9.43	36.0

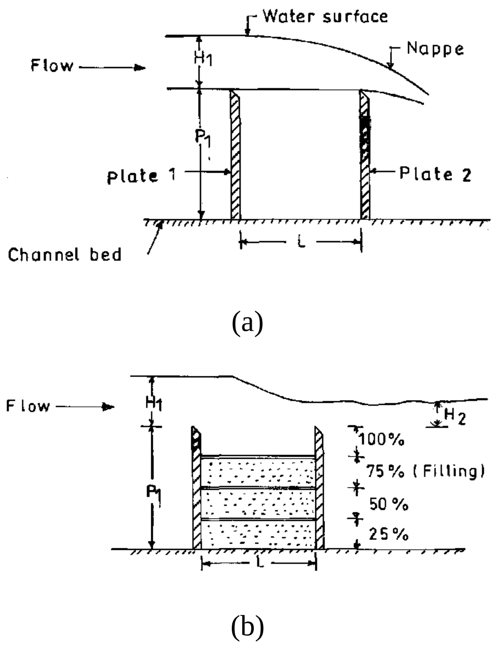

Figure 2. Sectional view of twin plate weir (a) free flow and (b) submerged flow conditions with filling.

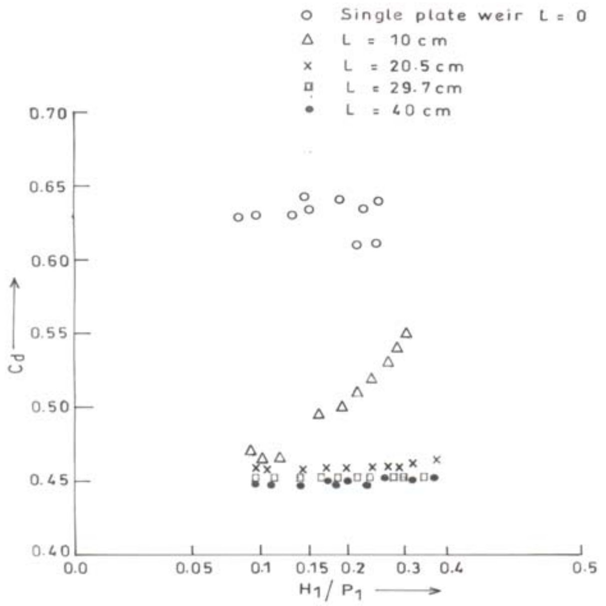

Figure 3. Effect of spacing of twin plate weir on c_d.

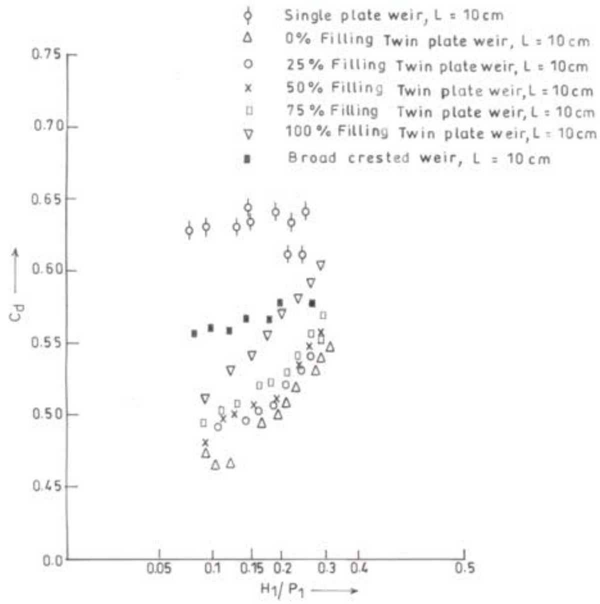

Figure 4. Effect of % of filling on c_d.

material up to 25 %, 50 %, 75 % and 100 % of the weir height. From experimental data, a graph is plotted between Cd and H_1/P_1 for each filling as shown in Figure 4. It is observed that, as the % of filling increases the value of Cd increases exponentially, for any value of H_1/P_1. It is also seen that with no filling increase, the Cd value is at minimum, while for sharp crested weir the Cd value is maximum. The value of Cd increases gradually for filling from 25 % to 100 %. The points of broad crested weir are coming close to 100 % filling for a twin plate weir. It is possibly because weir starts behaving as a solid broad crested weir and space between two plates can be used for deposition of sediments with time without affecting the performance.

5.3. Critical Submergence Ratio The values of critical submergence are given in Table 3 and have been plotted in Figure 5 for different spacing of twin plates. It can be seen from the Figure 5 that for any value of $Q_t\ L/Q_{sl}\ P_1$ (where Q_t is total discharge, Q_{sl} is sharp crested weir discharge) the critical submergence increases irrespective of spacing between the plates. A higher value of critical submergence indicates more practical utility of the device compared with single plate weir or broad crested weir.

5.4. Calculation of Discharge Two plots have been suggested between Q Vs H_1 and Q vs H_2/H_1 for free and submerged flow conditions as shown in Figures 6 and 7 respectively. Both curves are showing increasing trend and later on follows asymptotic path. With free flow, head measurement at a location upstream, determines discharge with the knowledge of weir size and shape. Downstream water rising above the weir crest elevation produces a submerged weir condition. When the downstream water surface is near or above the crest elevation of a sharp-crested weir, accuracy of measurement should not be expected. For any measured value of H_1 or H_2/H_1, these curves (Figures 6 and 7) can be used for finding out discharge under free and submerged flow conditions for any spacing of the twin plates with in the experimental range, tested in the present work.

6. CONCLUSIONS

Following conclusions are drawn from the present study.

TABLE 3. Critical Submergence Ratios for Different Spacing of Twin Plates.

S No.	Q (10^{-3} m^3/s.)	Spacing Between Plates (L) in cm	Critical Submergence (H_2/H_1) (%)
1	08.83	10.0	56.56
2	15.46	10.0	66.14
3	26.02	10.0	75.23
4	30.98	10.0	79.17
5	07.27	20.5	56.56
6	10.21	20.5	66.25
7	14.70	20.5	69.40
8	21.46	20.5	78.20
9	28.80	29.7	86.05
10	09.42	29.7	63.30
11	15.69	29.7	73.00
12	21.11	29.7	79.84
13	29.05	29.7	88.16
14	36.50	40.0	95.50
15	09.43	40.0	65.00
16	13.75	40.0	70.85
17	17.72	40.0	76.70
18	27.07	40.0	86.89
19	36.01	40.0	96.99

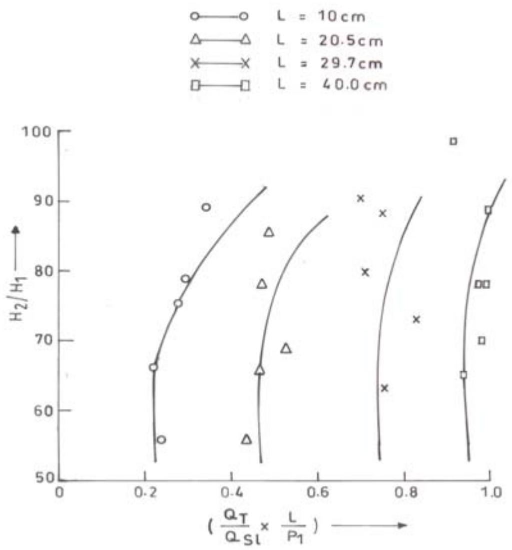

Figure 5. Variation of critical submergence with discharge for different spacing of twin plates, weir.

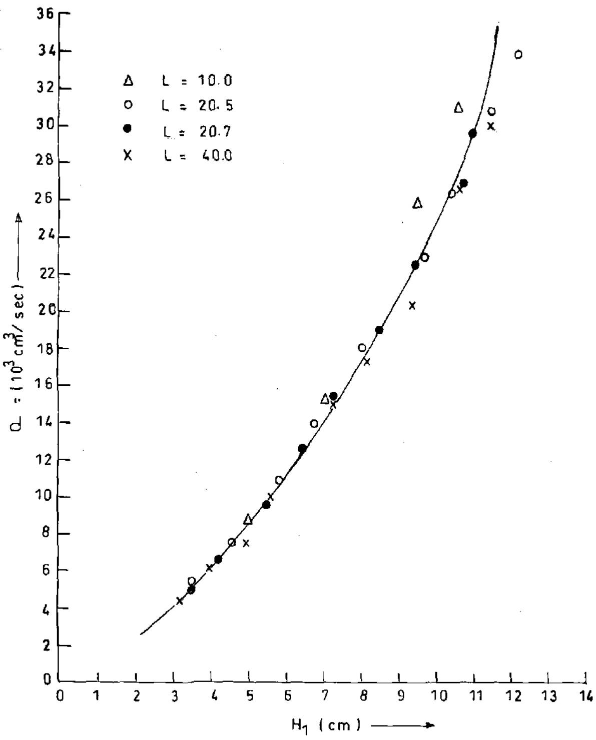

Figure 6. Variation of discharge with upstream head for different spacing of plates (free flow).

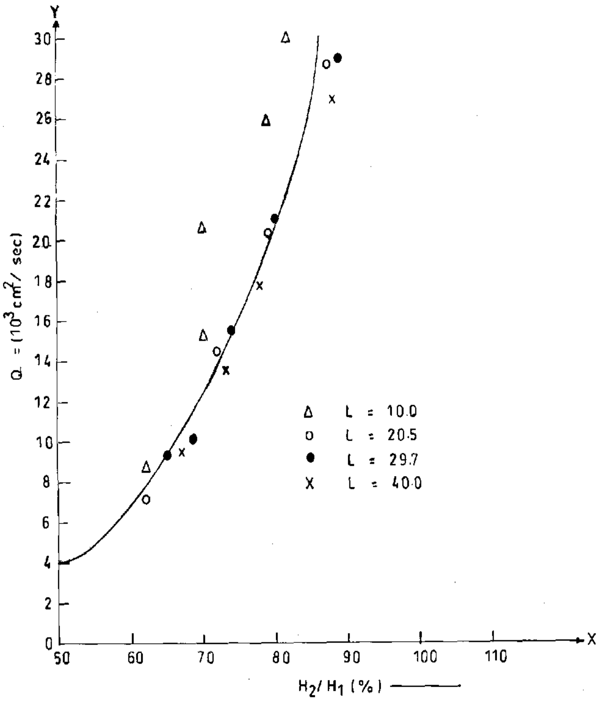

Figure 7. Variation of discharge with submergence ratio for different spacing of plates (submerged flow).

1. It is seen that as spacing (L) between twin plates weir increases, the value of Cd decreases, hence discharge decreases for the same head of the weir.
2. As the value of H_1/P increases, Cd also increases but the increase in Cd is gradual for low value of H_1/P.
3. As % of filling in the space between the two plates increases, the value of Cd increases. The 100 % filling of twin plates starts behaving as a broad crested weir.
4. The critical submergence ratio is dependent on spacing of twin plate weir, a discharge value. Or a constant value of Q_t L/Q_{sl} P_1 and spacing of the plates, the critical submergence ration increases.
5. The developed graphs (Figures 6 and 7) can be used to find discharge under free and submerged flow conditions easily, just noting the upstream and downstream heads for any spacing of the twin plates within the experimental range.

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