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Flow Characteristics of Sharp-Crested Triangular Planform Contracted weirs

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Abstract

Weirs are a barrier across a river to amend its flow characteristics. They have been widely used for the purpose of flow measurement and control. Weirs are usually in the form of obstructions smaller than most conventional dams, which cause water to pool behind them, while allowing water to flow steadily over their tops pose problems of submergence upstream of the weir due to large afflux required to pass the discharge downstream. Various weirs of modified plan form have been suggested in the past to enhance their discharging capacity with minimum head over the weirs and to restrict the afflux. Presented in this paper are results of the experimental study carried out to investigate the discharge characteristics of a sharp-crested contracted triangular planform weir under free flow conditions in a rectangular channel. The efficiency of the triangular planform weirs is found better than the normal weir. A discharge equation has been proposed for the given range of data and found that the proposed equation is within $\pm$*5% of the observed ones. Sensitivity of the weir, i.e., change of discharge due to unit change in head is also carried out which indicates that the weir is more sensitive at the low head and low vertex angle.*

Key words: *– triangular planform weir, flow measurement, vertex angle, discharge coefficient and open channel.*

1. Introduction

A weir is built across a stream in order to raise level of water on the upstream side and to allow the excess water to flow over its entire length to the downstream side. It is desirable to provide more flood storage and/or larger capacity for weirs to pass the probable maximum flood safely. If the weir cannot adequately pass the updated flood, it is needed to enhance the discharging capacity. Moreover, conventional weirs are also inherited with afflux and submergence of area upstream of the weir. Various weirs of modified planform like oblique weirs, diagonal weirs, Duckwill weirs, Labyrinth weirs etc. have been suggested in the past to enhance their discharging capacity with minimum head over the weirs and to restrict the afflux.

Labyrinth weirs are folded in plan view (i.e. the weir crest is not straight in planform) to provide a longer crest length compared with a normal weir having the same lateral space to increase the discharge for a given operating head. Since labyrinth weirs passes large flood at a comparatively low head, they can therefore be widely used to a particular advantage in situations where a weir is required to pass a range of discharge with a limited variation in upstream water levels and also where the width of a channel is restricted. For large reservoirs, the labyrinth weir also can be used as the overflow structure. It allows the overflow sill to be raised for the same maximum level of the water and flood, and thus, increase the storage capacity of the reservoir.

Discharge (Q) over a sharp-crested suppressed weir under free flow condition in a channel is expressed in terms of the following mathematical expression

$$Q = \frac{2}{3} C_d \sqrt{2g} L H^{\frac{3}{2}} \quad (1)$$

Where C_d = coefficient of discharge, L = crest length of the weir, g = acceleration due to gravity, H = head over the crest. The C_d depends on flow characteristics and geometry of the channel and the weir (Bagheri S, Heidarpour M., 2010).

For a sharp crested weir with end contraction, if velocity of approach is considered then equation (1) is modified as:

$$Q = \frac{2}{3} C_d \sqrt{2g} \left[L - 0.1n \left(H + \frac{V_a^2}{2g} \right) \right] \left[\left(H + \frac{V_a^2}{2g} \right)^{\frac{3}{2}} - \left(\frac{V_a^2}{2g} \right)^{\frac{3}{2}} \right] \quad (2)$$

Where n is the numbers of end contractions, $V_a = \frac{Q}{B(H+P)}$ is velocity of approach, B is width of the flume and P is weir height.

Labyrinth weirs of various plan forms like trapezoidal, rectangular, triangular etc. and also a combination of these have been used in practice. This weir may be of one fold or multiple folds as per the requirement and may be sharp-crested or broad. An extensive investigation dealing with the behavior of the labyrinth weirs was performed by Taylor (1968). He presented his results in the term of a magnification ratio i.e., ratio of discharge over labyrinth weir and normal weir for the same head over the crest. Hay and Taylor (1969, 1970) tested various plan shapes in the form of labyrinth weirs and presented the results in the form of curves between the ratio of discharge over labyrinth weir (Q) to corresponding normal weir (Q_n) and h/w. where, w = weir height. They found that the triangular planform weir is more efficient than the trapezoidal plan form.

Tullis et al. (1995) studied labyrinth weirs having trapezoidal plan form. They found the capacity of a labyrinth weir is a function of the total head, the effective crest length and the coefficient of discharge. The coefficient of discharge depends on weir height, total head, weir wall thickness, crest shape, vertex configuration and the angle of the side legs. Tullis et al. (2007) conducted experiments on three submerged labyrinth weirs of different geometries with half-round crest shapes. They described the submerged labyrinth weir head–discharge relationship using the dimensionless submerged head parameters and found that the relationship is independent of labyrinth weir sidewall angles.

Aeration performances of different planforms of labyrinth weirs have been studied by various investigators [Wormleaton et.al. (1998, 2000), Emiroglu et.al. (2005)] and they found that the geometry of labyrinth weirs provides increased sill length and often results in the overfall jets colliding with each other, both of which may lead to increased aeration. They found that the aeration efficiency of the labyrinth weirs generally is better than the equivalent-length linear weir and it increases as the weir included angle becomes smaller and also at lower overfall drop heights and higher discharges. Emiroglu et al. (2010) and Bilhan et al. (2010) studied the hydraulics of weir using soft computing techniques.

Kumar et al. (2011, 2013) conducted an experimental study to investigate the discharging capacity of a sharp-crested suppressed triangular and curved plan form weir under free flow conditions in a rectangular channel. They found that the efficiency of the triangular and curved plan form weirs was better than the normal weir. Sensitivity of the weir, i.e., change of discharge due to unit change in head was also carried out which indicated that the weir was more sensitive at the low head and low vertex angle.

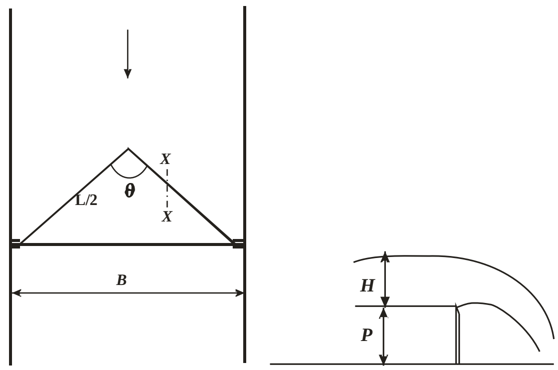
Presented in this paper are results of the experimental study carried out to investigate the discharge characteristics of a sharp crested triangular planform weir with end contraction under free flow condition in a rectangular channel. It is intended that the triangular planform weir will discharge more compared to normal weir for the same head of water.

2. Materials and Methods

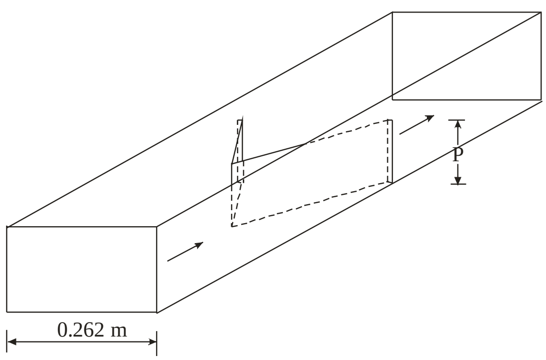
2.1Experimental work

The experiments were conducted in a horizontal rectangular tilting flume of length 5.360 m; width 0.262 m and depth 0.450 m in the hydraulics lab of Graphic Era University, Dehradun, India. Sharp-crested triangular planform weirs were fabricated of mild steel plates and were located at 5.150 m downstream from the head of the flume. Head over the crest was measured using the point gauge of accuracy ± 0.1 mm and discharge by means of an orifice meter provided in the inlet pipe and connected to the pressure gauges. Water was guided to a sump provided at the end of the flume in the downstream of the weir to ensure free flow condition. Regulating gate and wave suppressors were provided at the upstream of the flume to control the discharge and to dissipate the surface disturbances, respectively.

The experiments were performed for weirs of vertex angle ¯ = 180^0, 150^0, 135^0, 120^0, 105^0, 90^0, 75^0 and 60^0 and for each vertex angle for varying discharges. Fig. 1 shows the definition sketch of a sharp crested triangular planform weir with end contraction and Fig. 2 shows the layout of the experimental set-up. For each run, the head over the crest of the weir was measured at about 4–5 times upstream of the weir using point gage to avoid the curvature effect. The ranges of the data collected in the present study are given in Table 1.



(a)Plan (b) Section X-X



(c) 3D View of the weir and the flume

Fig. 1 Definition sketch of sharp crested triangular planform contracted weir

Table 1 Range of parameters

S.no	– (degree)	*P* (m)	*H* (m)	Q_o (m^3/s)	No. of Runs
1	180	0.1043	0.0314 – 0.0777	0.0022 – 0.0091	10
2	150	0.1040	0.0362 – 0.0834	0.0031 – 0.0101	14
3	135	0.1033	0.0273 – 0.0812	0.0022 – 0.0094	13
4	120	0.1022	0.0259 – 0.0847	0.0022 – 0.0103	12
5	105	0.0992	0.0237 – 0.0754	0.0022 – 0.0094	12
6	90	0.1009	0.0224 – 0.0721	0.0022 -0.0096	13
7	75	0.1019	0.0309 – 0.0690	0.0038 – 0.0099	12
8	60	0.0995	0.0248 – 0.0541	0.0031 – 0.0094	13

3. Analysis of Data

3.1. Data Presentation and Analysis

Data collected in the present study is analyzed to obtain the functional relationship of discharge coefficient for all tested triangular planform contracted weirs in a free flow situation in the form of Rehbock's (1929) equation. i.e.

$$C_d = a + b\left(\frac{H}{P}\right) \qquad (3)$$

Where *a* and *b* are the coefficients to be found using experimental data. The most general values for these coefficients are proposed by Rehbock as *a* = 0.611 and *b* = 0.075.

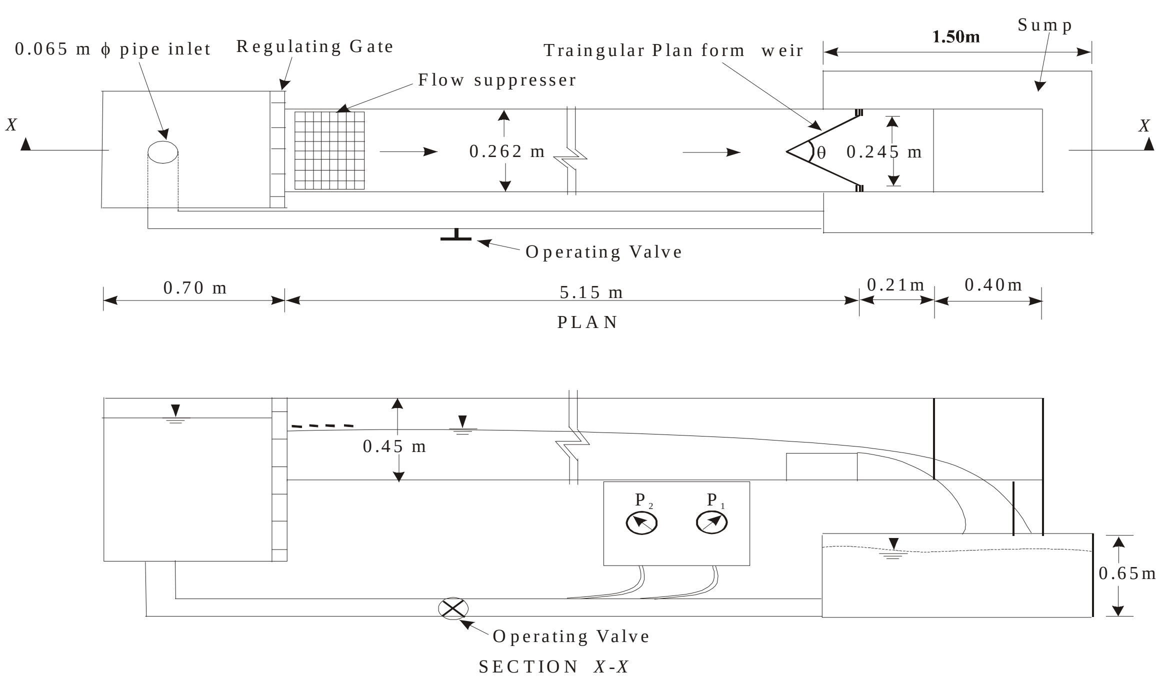


Fig. 2 Layout of experimental set-up

Variation of observed discharge with head over the crest for the triangular planform contracted weirs of different vertex angles is shown in Fig. 3. All the plots are curvilinear, co-focal with the best one being for the largest skew length, i.e. $\theta = 60^0$. Fig. 3 clearly indicates that for the same value of *H*, discharge increases with the decrease of vertex angle due to increases of the crest length of the weir. For each data set, the C_d was computed using Eq. (2) for known value of discharge, head over the crest and the crest length for weirs of different vertex angles.

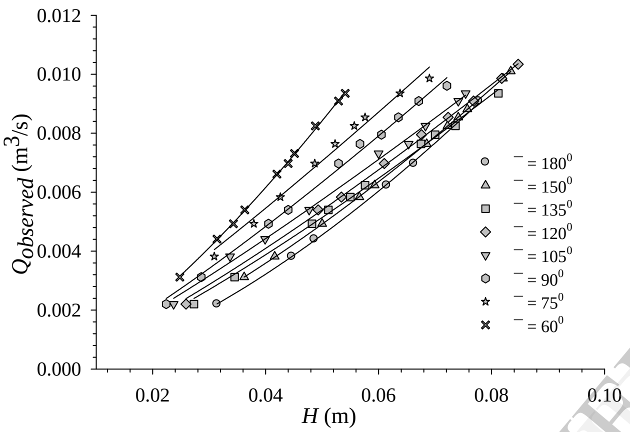


Fig. 3 Variation of $Q_{observed}$ with H for weirs of different vertex angles

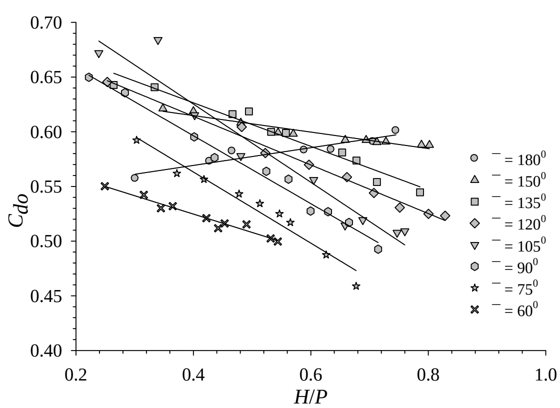


Fig. 4 Variation of C_d with H/P for weirs of different vertex angles

Variation of C_d with H/P is shown in Fig. 4 for the weirs of different vertex angles. It can be noted that C_d decreases with an decrease of vertex angle due to interference of the falling jets for high value of H/P. However, for the low value of H/P, the interference of jets is not so severe, resulting in high C_d. The value of C_d decreases with increase in H/P for different vertex angle and for the vertex angle 180° i.e., the normal weir, the C_d increases with H/P, which satisfies the Rehbock (1929) equation for C_d.

3.2 Discharge equation for triangular planform contracted weir

Invoking the Rehbock equation, the variation of C_d with H/P is fitted to linear equations for weirs of different vertex angles as follows:

$$C_d = 0.537 + 0.081\,(H/P) \quad \text{For } \theta = 180^0 \quad R^2 = 0.89 \qquad (4a)$$
$$C_d = 0.645 - 0.075\,(H/P) \quad \text{For } \theta = 150^0 \quad R^2 = 0.94 \qquad (4b)$$
$$C_d = 0.706 - 0.199\,(H/P) \quad \text{For } \theta = 135^0 \quad R^2 = 0.96 \qquad (4c)$$
$$C_d = 0.703 - 0.222\,(H/P) \quad \text{For } \theta = 120^0 \quad R^2 = 0.98 \qquad (4d)$$
$$C_d = 0.768 - 0.358\,(H/P) \quad \text{For } \theta = 105^0 \quad R^2 = 0.94 \qquad (4e)$$
$$C_d = 0.721 - 0.310\,(H/P) \quad \text{For } \theta = 90^0 \quad R^2 = 0.98 \qquad (4f)$$
$$C_d = 0.693 - 0.325\,(H/P) \quad \text{For } \theta = 75^0 \quad R^2 = 0.95 \qquad (4g)$$
$$C_d = 0.592 - 0.168\,(H/P) \quad \text{For } \theta = 60^0 \quad R^2 = 0.96 \qquad (4h)$$

A high correlation between C_d and H/P may be noted for all the weirs. Variations of constants '*a*' and '*b*' with central angle are shown in Fig. 5. A second order polynomial has been fitted to the data for '*a*' and '*b*' as follows (angles are in radian):

$$a = -0.148\theta^2 + 0.574\theta + 0.176, \quad R^2 = 0.90 \qquad (5a)$$
$$b = 0.192\theta^2 - 0.644\theta + 0.239, \quad R^2 = 0.89 \qquad (5b)$$

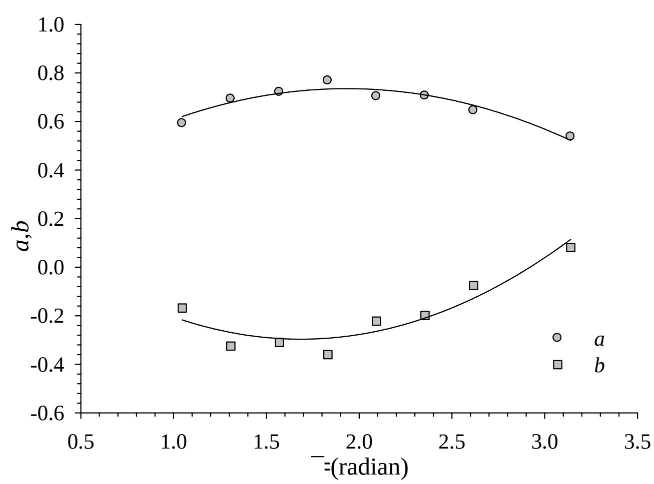


Fig. 5 Variation of '*a*' and '*b*' with θ

Out of 99 data sets for triangular planform contracted weirs, 75 data sets were used to develop the relationship for coefficient of discharge. The generalized equation of C_d for the triangular planform contracted weir to be used in Eq. (2) for the computation of discharge can be written as:

$$C_d = \left(-0.148\theta^2 + 0.574\theta + 0.176\right) + \left(0.192\theta^2 - 0.644\theta + 0.239\right)\left(\frac{H}{P}\right) \quad (6)$$

This equation is valid in the range $0 < H/P < 0.83$ and $60^\circ \le \theta \le 180^0$.

3.3 Validation of the proposed discharge equation

The remaining 24 data sets, not used in the derivation of Eq. (6), were used next to validate the proposed relationship for C_d i.e., Eq. (6). The computed discharge is compared with the corresponding observed ones in Fig. 6, which shows that the computed discharge is within ±05% of the observed ones for the weirs of all vertex angles studied herein. For a numerical measure for error between the observed and computed values, an average percentage error term e is defined as (Ghodsian M., 2003):

$$e = \frac{100}{N}\sum_{i=1}^{N}\left[\frac{Q_{computed} - Q_{observed}}{Q_{observed}}\right] \quad (7)$$

The average percentage error in the computation of discharge over the weir using Eqs. (2) and (6) is found in the range 0%–05% for weirs of different vertex angles.

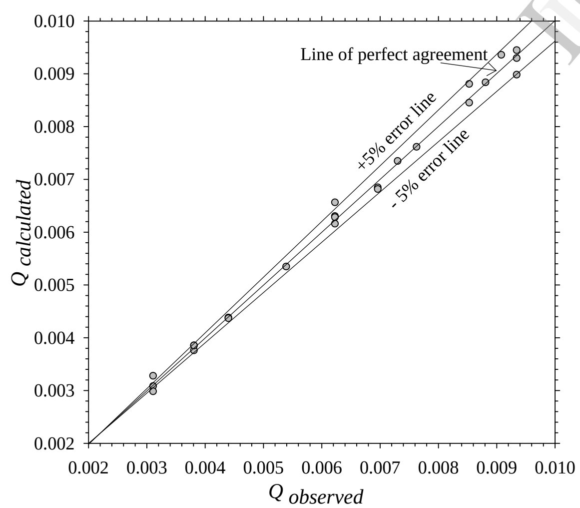


Fig. 6 Comparison of computed discharge using Eqs. (2) and (6) with the observed ones

3.4 Efficiency of the weir

An efficient weir passes more discharge for constant head and length of weir compared to the other. To examine the efficiency of the triangular planform contracted weir for different vertex angles, ratio of discharges over the triangular planform contracted weir and normal weir, i.e., Q/Q_n is plotted with H/P in Fig. 7.

The efficiency of triangular planform contracted weir is high for low central angle and decreases with increase of H/P due to interference of the jets downstream. For $H/P = 0.05$, the weirs of vertex angle 150^0, 135^0, 120^0, 105^0, 90^0, 75^0 and 60^0 are respectively 1.53, 1.88, 1.99, 2.63, 2.47,3.14 and 2.35 times more efficient than the normal weir. However, for $H/P = 1.0$, the efficiency of triangular planform contracted weir is low and even for $\theta = 60^0$, the efficiency is only 1.55 times the normal weir.

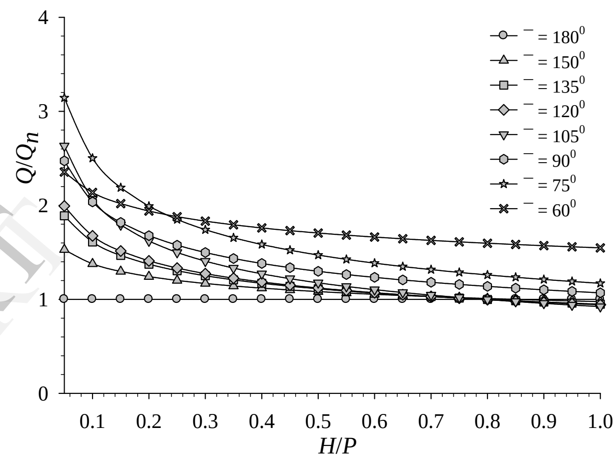


Fig. 7 Variation of Q/Qn with H/P for the weirs of different vertex angles

3.5 Sensitivity analysis of the triangular planform contracted weir

Sensitivity analysis, i.e., change in discharge due to unit change in the head of water is carried out for the proposed discharge equation of the triangular planform contracted weir, which can be written as:

$$Q = \frac{2}{3}\left[a + b\left(\frac{H}{P}\right)\right]\sqrt{2g}\left[L - 0.1n\left(H + \frac{V_a^2}{2g}\right)\right]\left[\left(H + \frac{V_a^2}{2g}\right)^{\frac{3}{2}} - \left(\frac{V_a^2}{2g}\right)^{\frac{3}{2}}\right] \quad (8)$$

The values of 'a' and 'b' can be obtained from the Eqs. (5a) and (5b) respectively. Differentiating Q with respect to H and arranging the terms, one can get

$$\frac{dQ}{dH} = \frac{3}{2}Q\left[\frac{\left(H + \frac{V_a^2}{2g}\right)^{\frac{1}{2}}}{\left(H + \frac{V_a^2}{2g}\right)^{\frac{3}{2}} - \left(\frac{V_a^2}{2g}\right)^{\frac{3}{2}}} - \frac{n}{\left\{L - 0.1n\left(H + \frac{V_a^2}{2g}\right)\right\}} + \frac{2b}{3P\left\{a + b\left(\frac{H}{P}\right)\right\}}\right] \quad (9)$$

The larger value of dQ/dH implies higher sensitivity. Data collected in the present study was used to compute dQ/dH for different values of the vertex angles. The variation of dQ/dH with H is depicted in the Fig. 8. A perusal of Fig. 8 reveals that the discharge through triangular planform contracted weir is more sensitive to the low head. As the head increases, the sensitivity decreases due to interference of the water jet downstream of the weir crest. Further, sensitivity is higher for the low vertex angle of the triangular planform contracted weir due to large weir crest length.

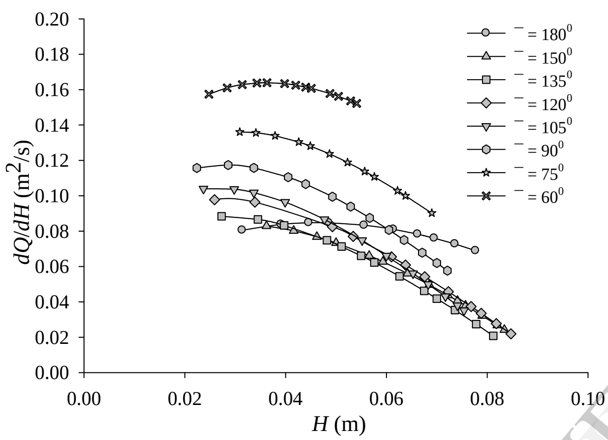


Fig. 8 Sensitivity of the curved weirs as function of head

4. Conclusion

An experimental study was carried out to investigate the discharging capacity of a sharp-crested triangular planform contracted weir under free flow conditions in a rectangular channel. The coefficient of discharge of the triangular planform contracted weir decreases with decrease of vertex angle due to interference of falling jets for high value of H/P. However, for low values of H/P and higher values of vertex angle, the C_d is high. The computed discharge using the proposed equation is within $\pm$05% of the observed ones. The efficiency of the curved weir is high for low vertex angle and decreases with increase of H/P due to interference of the jets downstream. For H/P = 0.05, the weirs of vertex angle 150^0, 135^0, 120^0, 105^0, 90^0, 75^0 and 60^0 are respectively 1.53, 1.88, 1.99, 2.63, 2.47,3.14 and 2.35 times more efficient than the normal weir. However, for H/P = 1.0, the efficiency of triangular planform contracted weir is low for all vertex angles. Sensitivity analysis indicates that the discharge through triangular planform contracted weir is more sensitive to the low head and low vertex angles. As the head increases, the sensitivity decreases due to interference of the water jet downstream of the weir crest.

Notations

B	=	flume width
C_d	=	coefficient of discharge for triangular planform contracted weir
g	=	acceleration due to gravity
H	=	head over the weir
L	=	crest length
n	=	numbers of end contractions.
P	=	weir height above the bed of flume
Q	=	discharge over triangular planform contracted Weir
Q_0	=	observed Discharge
Q_c	=	computed Discharge
Q_n	=	discharge over corresponding normal weir
V_a	=	velocity of approach
‾	=	vertex angle
a, b	=	coefficients

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