Portable central baffle flume

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Abstract

This paper investigated the hydraulic characteristics of the triangular central baffle (TCB) flume. Laboratory tests were carried out to determine the flume dimensions. The field applicability of the proposed portable device was examined by on-farm installation. According to the laboratory tests, when the contraction ratio, *r*, was less than 0.39, the flow capacity was not affected by the ratio between the flume's floor height and the throat width. The laboratory analysis also showed that there was no significant effect of installing an entrance ramp on the stage-discharge relationship for $r \leq 0.39$, while the entrance ramp increased the discharge capacity for $r>0.39$. The stage-discharge curve obtained based on the laboratory tests was verified using field data. The results revealed that the proposed portable flume could be used accurately to determine the flow through an unlined ditch. Practical suggestions were proposed to determine the distinguishing condition curve.

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Introduction

A central baffle flume consisting of an obstacle inserted in the channel axis is a measuring structure whose design criteria are developing. For example, taking a circular cone as the central baffle, Hager (1985) proposed a stage-discharge formula for a trapezoidal flume. A circular mobile flume consisting of two pieces of pipes, one installed vertically through another, is a kind of central baffle flume (Hager, 1989; Samani *et al.,* 1991; Kolavani *et al.,* 2019).

Applying the dimensional analysis and the self-similarity theory and using the experimental data provided by Peruginelli and Bonacci (1995), Ferro (2016) proposed the following stage-discharge formula:

$$\frac{Q^{2/3}}{B_c^{5/3} g^{1/3}} = a\left(\frac{h}{B_c}\right)^n \quad (1)$$

where, Q is discharge, B_c (=B-b) is throat width, B is channel width, b is baffle width, h is upstream flow depth, g is the acceleration due to gravity, and a and n are coefficients to be estimated by using experimental data. Equation (1) is applicable for a central baffle installed in a rectangular channel cross-section.

Samani (2017) investigated the field application of three simple flow measuring devices and proposed the application of mobile flumes for circular, trapezoidal, and rectangular channel cross-sections. A circular pipe installed vertically was considered the central baffle for circular and trapezoidal flumes, while for the rectangular case, he proposed using two half-pipes glued at the channel walls.

Ferro (2018), using the field measurements carried out by Samani (2017), tested the applicability of the proposed theoretical stage-discharge relationships for the case of both a flume with two semi-cylindrical glued at the channel walls and a circular flume in which a column pipe is installed at the middle of the main pipe.

Lotfi Kolavani *et al.* (2019) investigated the flow through a central baffle flume to quantify the impact of the throat length, *L*, and apex angle, α, on the stage-discharge relationship. They proposed a central baffle flume with an entrance apex angle of 75° and no guide wall installation, *i.e.*, *L*=0, to minimise the construction costs.

Bijankhan and Ferro (2019) investigated the flow through a triangular central baffle (TCB) flume and, using the dimensional analysis and self-similarity theory, proposed the following stage-discharge formula:

$$\frac{Q}{B_c^{\frac{5}{2}} g^{\frac{1}{2}}} = 0.6925\left(\frac{h}{B_c}\right)^{1.5734} \quad (2)$$

Equation (2) is applicable for a triangular baffle with an apex angle of 75° and $0.17 \leq B_c/B \leq 0.76$ (Bijankhan and Ferro, 2019).

Kapoor *et al.* (2019) developed the design criteria for a mobile conical central baffle flume. A cone-shaped structure like the central baffle has the advantage of measuring a wider range of flow rates and being more stable against the water current.

The central baffle flume concept could be used for developing a simple portable flume. The structural sketch of the portable triangular central baffle (TCB) flume was proposed in this study. The TCB flume's structural shape led to evaluating the effects of the floor height, p, and an entrance ramp on the stage-discharge relationship. To this end, different combinations of floor height and entrance ramp dimensions were fabricated, and their effects were evaluated on the rating curves. Then this information was used to finalise the dimensions of a simple portable flume and the associated stage-discharge formula. Field measurements indicated that the stage-discharge formula developed based on laboratory data could be used accurately to determine the flow rate through the portable TCB flume.

Materials and methods

Laboratory tests

Structural shape of the portable triangular central baffle

Figure 1A shows the structural shape of the portable TCB flume proposed in this study. The proposed flume is used for on-farm applications and unlined ditches. As shown, the triangular central baffle was located on a flume floor. When installing the flume, it should be pushed into the soil until the flume floor is levelled with the canal bed. This would ensure stability and no leakage issues. However, in coarse grain size soils or rocky beds, it may not be possible to push it completely into the soil, and therefore the flume floor height might act as an entrance sill whose effect should be determined. The proposed device is a portable TCB, and it is not aimed to recommend a central baffle flume installed on a sill. Sill condition is an exceptional condition that may only occur when the device cannot be installed correctly.

A triangular central baffle of the apex angle of 75° was located on a flume floor of 0.4 m in width and 0.5 m in length. Guide walls of the given dimensions, as shown in Figure 1B, were proposed to make a transition from the width of 0.4 m to 0.5 m. Figure 1C indicates the portable TCB flume inserted in the experimental channel to obtain the associated stage-discharge curve. The experiments were conducted in a 0.5 m wide, 0.6 m high, and 12 m long Plexiglas flume located at the hydraulic laboratory of the water engineering Department, Imam Khomeini International University (IKIU), Qazvin, Iran.

Floor height and entrance ramp

As shown in Figure 2, the triangular central baffles of different widths were inserted into the experimental channel to investigate the effects of the floor height and an entrance ramp. To this end, the floor heights of ρ=0, ρ=10 (it was 10.3 in some cases), and ρ=15 cm were tested (Table 1). Taking entrance ramp slopes (Figure 2) of β=0, 12, and 45 degrees with ρ=11 cm, the role of β was investigated for different central baffle widths (Table 2).

The tests were carried out in a steady-state flow condition. A magnetic flow meter measured the flow rate with an accuracy of ±0.5% of the full scale. Point gauges were used to record the flow depths of both upstream and downstream flume sections. The upstream flow level was recorded at the channel centreline and from the floor height. The swelling effect was marginal due to the triangular shape of the central baffle. However, the upstream flow

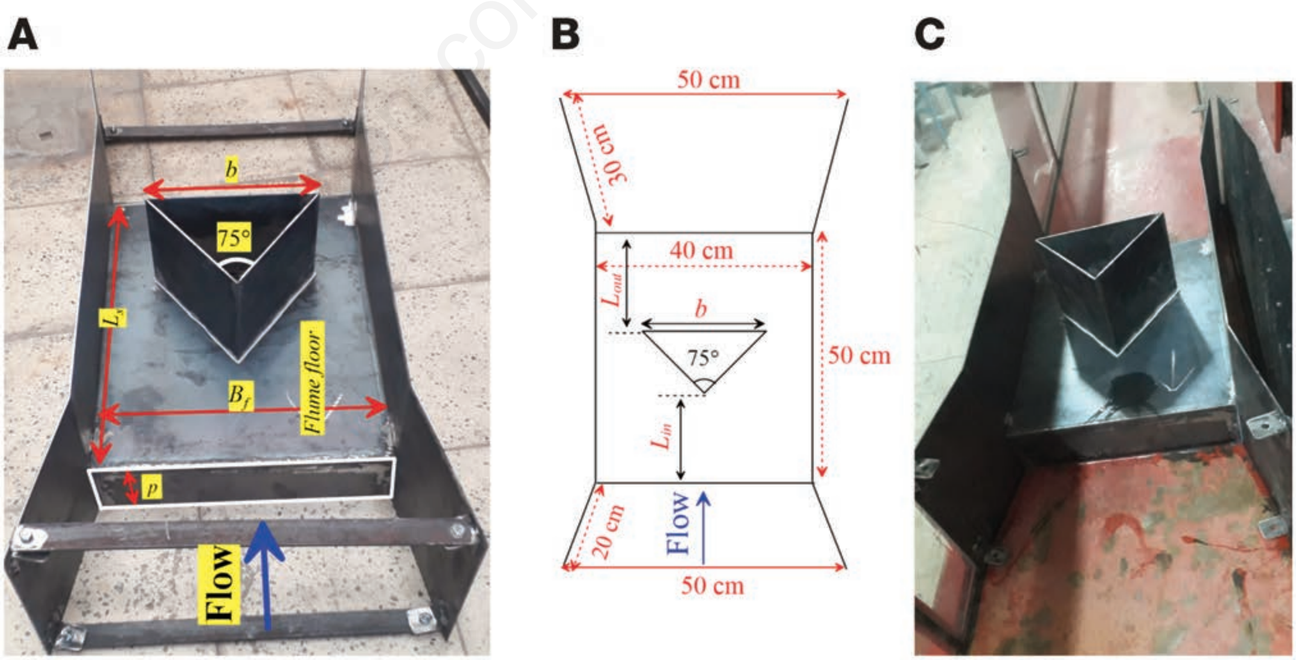

Figure 1. Portable triangular central baffle (TCB) flume for on-farm use: A) dimensions and structural shape; B) schematic view; C) Portable TCB flume inserted into the experimental channel (the total TCB flume height is 0.3 m and L_{in}=L_{out}).

depth was recorded at 5 cm upstream of the central baffle apex. The tailwater flow depth was measured from the channel bed and at the channel centerline. No water level fluctuation was observed at the upstream pool. Note that all experimental runs were carried out with the TCB flume placed in a horizontal channel.

Finally, the distinguishing condition curve representing the maximum tailwater depth for a free flow condition (submergence threshold) was formulated using the experimental data of different floor heights, entrance ramp slopes, and B_c/B values (Table 3).

A sill length L_s equal to 0.5 m was used in all experimental runs. As proposed by Lotfi Kolavani *et al.* (2019), a triangular central baffle with an entrance apex angle of 75° and installed at the sill centre was considered in this study. Free flow condition was considered in all experimental runs.

Testing the proposed portable flume

The portable flume of two central baffles with the widths of b=0.244 and 0.28 m (r=0.39 and 0.3) was tested. The flume was installed into the channel (Figure 1C), and the associated stage-discharge formula was obtained.

The upstream flow depth was recorded at 5 cm upstream of the central baffle apex. Tailwater depth was controlled using a tailgate installed at the channel end. The tailgate was fully open to ensure a free flow condition downstream of the portable central baffle structure. To achieve the submergence threshold, the tailgate was closed so that the upstream flow depth started increasing. Therefore, an upstream water level increase of 1-2 mm was considered the submergence threshold condition.

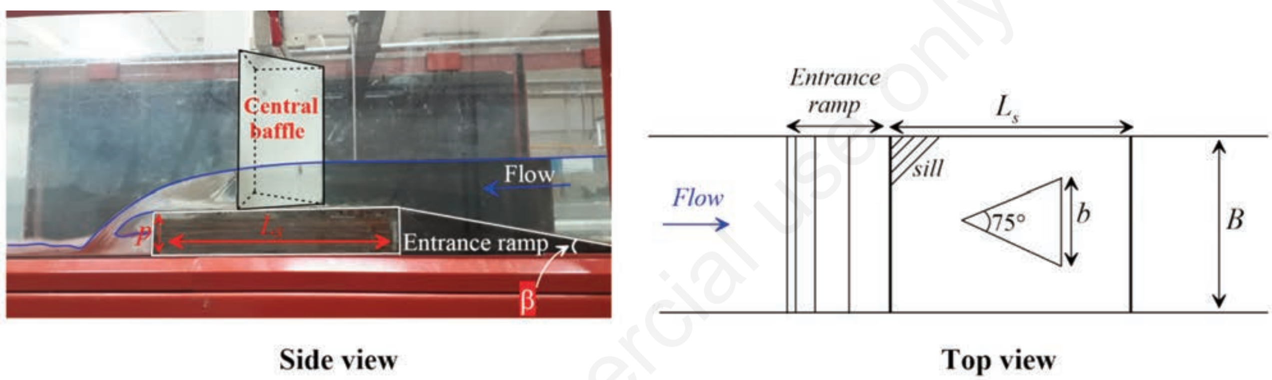

Figure 2. Triangular central baffle installed at the experimental flume (channel test).

Table 1. Experimental data ranges to investigate the floor height effect on the stage-discharge curve.

Floor height, p (cm)	B_c/B	Q (l/s)	h (cm)
0	0.17, 0.39, 0.56,0.76	3.5-45.65	2.9-29
10 and 10.3	0.17, 0.39, 0.56,0.76	1.23-46.49	2.7-26.3
15	0.17, 0.56, 0.76	1.41-47.53	2-22.3

Table 2. Experimental data ranges to investigate the entrance ramp slope on the stage-discharge curve.

Entrance ramp slope (degree)	B_c/B	Q (l/s)	h (cm)
0	0.17, 0.39, 0.56, 0.76	3.14-32.39	3.6-26.3
11.3	0.17, 0.39, 0.59	3.44-40	3.5-30.4
45	0.17, 0.39, 0.59	5.28-34.72	4.7-27.5

Table 3. Experimental data ranges for investigating the distinguishing condition curve.

Floor height, p (cm)	Entrance ramp slope (degree)	B_c/B	Q (l/s)	h (cm)	h_{th} (cm)
0	0	0.17, 0.39, 0.56, 0.76	0.85-45.65	1.4-29	1.4-15.1
10 (or 10.3)	0	0.17, 0.39, 0.56, 0.76	3.14-32.39	3.9-26.6	12.4-20.8
11	0, 11.3, 45	0.17, 0.39, 0.56, 0.76	3.14-40	3.5-34	12.5-22.8
15	0	0.17, 0.76	1.83-12.42	2-14.9	16.6-21.2

Field testing of the portable triangular central baffle flume

Field measurements were performed to assess the performance of the proposed portable TCB flume. The tests were performed in the research farm of the Water Engineering Department at Imam Khomeini International University, IKIU, Qazvin, Iran.

A portable flume with b=24.4 *cm* (L_{in}=L_{out}=17 *cm*) was installed at the ditch entrance supplied by an old Qanat, a system for transporting water from an aquifer or water well to the surface used in Iran, TCB flume was placed in the ditch horizontally. It was pushed into the soil to level the ditch bed and flume floor (Figure 3A). In such a condition, the flume was stable, and the flume leakage was minimised. In the downstream section, the soil bed was slightly deeper to ensure a free overfall and a free flow condition, as shown in Figure 3B and C. The flow rate was determined by measuring the required time to fill a 32 L reservoir. The upstream flow depth was measured using a ruler at 5 cm upstream of the central baffle apex (Figure 3C). Finally, the associated laboratory-derived rating curve of the portable device was compared with the field measurements.

Dimensional analysis

The free flow hydraulic of the central baffle flume with a floor height of p, equipped with an entrance ramp having a slope of tan β, could be expressed by the following functional relationship:

$$\varphi\left(h,Q,B_c,B,p,\tan\beta,g,\rho,\mu\right)=0 \tag{4}$$

where φ is a functional symbol, h is the upstream flow depth measured at 5 cm far from the upstream face of the central baffle, Q is discharge, B_c=B–b is the throat width, B is the approaching channel width, g is the acceleration due to gravity, ρ is water density and μ is the water viscosity.

Taking B_c, μ, and g, as reference variables and applying Buckingham's theorem of dimensional analysis, the following dimensionless groups are obtained:

$$\Pi_1=\frac{Q}{B_c^{5/2}\,g^{1/2}} \tag{4a}$$

$$\Pi_2=\frac{B_c}{B}=r \tag{4b}$$

$$\Pi_3=\frac{h}{B_c} \tag{4c}$$

$$\Pi_4=\frac{p}{B_c} \tag{4d}$$

$$\Pi_5=\tan\beta \tag{4e}$$

$$\Pi_6=\frac{\mu}{B_c^{3/2}g^{1/2}\rho} \tag{4f}$$

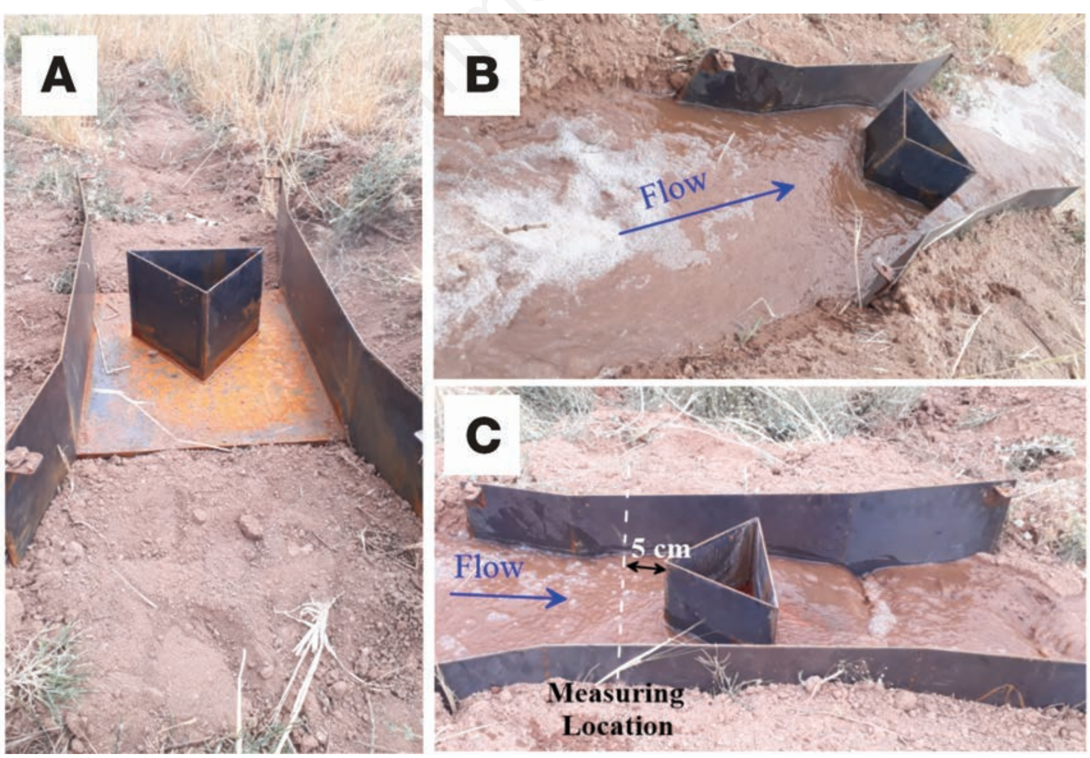

Figure 3. Portable triangular central baffle (TCB) flume: A) installation condition; B) flow through the measuring flume; C) reading the upstream flow depth.

Rearranging Eq. (4f), the following equation is obtained:

$$\Pi_{6,1,2}=\frac{\Pi_1\Pi_2}{\Pi_6}=\frac{B_c^{3/2}g^{1/2}\rho}{\mu}\frac{Q}{B_c^{5/2}g^{1/2}B}\frac{B_c}{B}=\frac{\rho Q}{\mu B}=\mathrm{Re} \quad (4g)$$

In which Re is the Reynolds number.

Taking Π_1 as the dependent dimensionless group, the dimensionless form of Eq. (3) is the following:

$$\frac{Q}{B_c^{5/2}\,g^{1/2}}=f\left(\frac{h}{B_c},\frac{p}{B_c},r,\tan\beta,\mathrm{Re}\right) \quad (5)$$

where f is a functional symbol.

For specific values of p/B_c, r, and tan β, when $h/B_c \rightarrow 0$ then $Q/[B_c^{5/2}\,g^{1/2}] \rightarrow 0$ and when $h/B_c \rightarrow \infty$ then $Q/[B_c^{5/2}\,g^{1/2}] \rightarrow \infty$. Therefore, according to the incomplete self-similarity (ISS) theory (Barenblatt, 1979, 1987), the group h/B_c can be extracted as a power type expression:

$$\frac{Q}{B_c^{5/2}\,g^{1/2}}=\left(\frac{h}{B_c}\right)^n f_1\left(\frac{p}{B_c},r,\tan\beta,\mathrm{Re}\right) \quad (6)$$

where n is a numerical constant to be obtained by experimental data and f_1 is a functional symbol. According to the experimental data of this study, the Reynolds number is in the range of $2.47\times10^6 \leq \mathrm{Re} \leq 9.51\times10^7$; therefore, viscous effects are small, and the Reynolds number may be neglected. Furthermore, the surface tension was neglected as previous studies showed that these effects are negligible except for very low values of the upstream flow depth (Rao and Shukla, 1971; Sargison 1972; Ranga Raju and Asawa, 1977; De Martino and Ragone, 1984).

Therefore, according to Eq. (6), the stage-discharge relationship is affected by the floor height ratio, p/B_c, the contraction ratio, r, and the entrance ramp slope, tan β.

Results and discussion

Effect of the floor height on the stage-discharge relationship

Flume bed rise may occur during the flume installation. To study the effect of the floor height, for a given value of the contraction ratio, r, the stage-discharge curves associated with different values of p/B_c were compared in Figure 4. Note that p/B_c=0 is an accurate flume installation in which no bed rise occurs. As shown, the floor height ratio, p/B_c, did not affect the stage-discharge curve

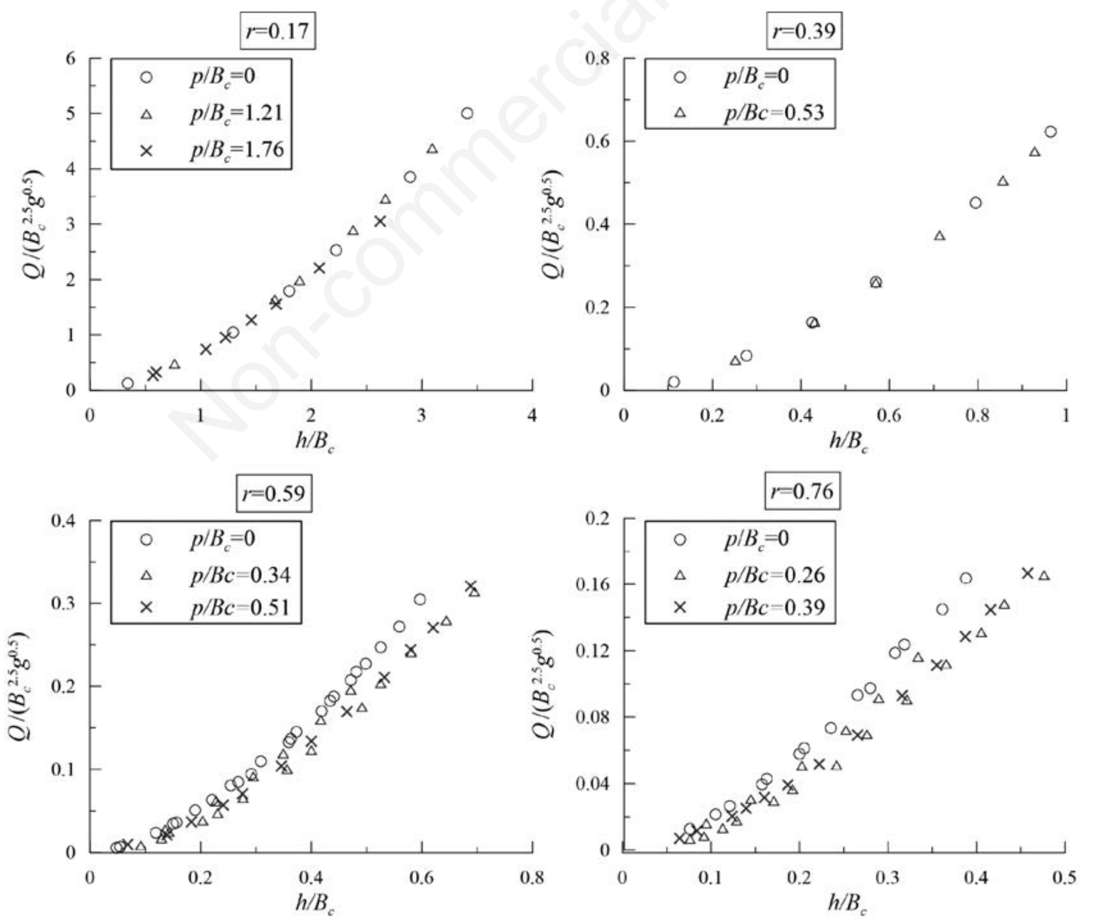

Figure 4. Effect of the floor height ratio, p/B_c, on the stage-discharge curve for different values of the contraction ratios.

for r=0.17 and 0.39. Consequently, the floor height ratio affects the flow capacity when the contraction ratio increases.

For a specific value of h/B_c, Figure 4 indicated that for r=0.59 and 0.79, a flume with no floor height, *i.e*., p/B_c=0, had a higher discharge capacity than the cases having p/B_c>0. This might be attributed to the fact that for r=0.59 and 0.79, the head loss due to the effect of p/B_c increases significantly.

Therefore, according to the experimental results of this study, it is suggested to consider a floor height ratio of $0 \leq p/B_c \leq 1.76$ with the contraction ratios of less than or equal to 0.39 to ensure that the floor height ratio does not influence the flow capacity. Consequently, the parameter p/B_c can be eliminated from the functional relationship Eq. (6) when $r \leq 0.39$.

Effect of the entrance ramp on the stage-discharge relationship

Taking p/B_c in the range of 0.27 to 1.76 and r=0.17 and 0.39, the stage-discharge curves associated with different entrance ramps slopes (tan β=0, 0.2, and 1) were plotted in Figure 5. This figure demonstrated that for $r \leq 0.39$, there was no significant effect of installing an entrance ramp on the stage-discharge curve. Consequently, the experimental investigation suggested taking b=0 to minimise the construction costs.

Taking r=0.59 and p/B_c=0.35, the effect of the entrance ramp slope on the stage-discharge curve was illustrated in Figure 6. As shown, for a specific value of h/B_c, the flume discharges associated with tan β=0.2 and tan β=1 were slightly higher than that obtained for tan β=0. In other words, an entrance ramp increases the discharge capacity when the contraction ratio is greater than 0.39.

In summary, the following recommendations are proposed: i) taking a contraction ratio in the range of $r \leq 0.39$, and a floor height ratio within the range of $0 \leq p/B_c \leq 1.76$, neither the floor height nor the entrance ramp slope affects the flume flow capacity; ii) for r>0.39 (the cases r=0.59 and 0.76 are tested in this study), both floor height and entrance ramp slope affect the stage-discharge formula. An increased floor height has a negative impact, while an entrance ramp slope increases the discharge capacity. As a practical conclusion, from the construction point of view and to minimise the flume weight, it is suggested to take $r \leq 0.39$, and a floor height ratio of $0 \leq p/B_c \leq 1.76$, for constructing the portable TCB flume. No entrance ramp installation is also suggested.

Calibrating the stage-discharge relationship by laboratory measurements

Central baffle flume

Taking $r \leq 0.39$, and a floor height ratio of $0 \leq p/B_c \leq 1.76$, for each value of the contraction ratio, r, the stage-discharge formula obtained by Eq. (6), depends only on the upstream head ratio, h/B_c:

$$\frac{Q}{B_c^{5/2}\, g^{1/2}} = m\left(\frac{h}{B_c}\right)^n \tag{7}$$

where, m and n are numerical constants. Eq. (7) is applicable when a central baffle is located in a channel, and the flume width is equal to the channel width. The parameters m=0.6808 and n=1.6286 were estimated, by a least-squares technique, using the experimental data of this study. As shown in Figure 7, Eq. (7) is applicable to estimate the flow rate within an error range of ±5% for 83.3% of the data points. The associated mean absolute relative error is 2.98%, which is acceptable for a flow measuring device. Scale effect may be significant for minimal upstream flow depth values. No high relative error was observed in Figure 7 for small upstream flow depths. However, the minimum upstream flow depth tested in this study was 2 cm. Therefore, the smaller flow depths should be avoided due to possible scale effects.

Portable triangular central baffle flume

According to the laboratory tests, when $r \leq 0.39$ and $0 \leq p/B_c \leq 1.76$ neither the floor height nor an entrance ramp slope affects the flume capacity. Therefore, no entrance ramp was considered to minimise the portable flume weight (Figure 1). Taking p=10 cm and B_c=12 and 15.6 cm (r=0.39 and 0.3), one may consider that the portable flume's stage-discharge formula would not be affected by floor height ratio. The flume width, B_f, was less than

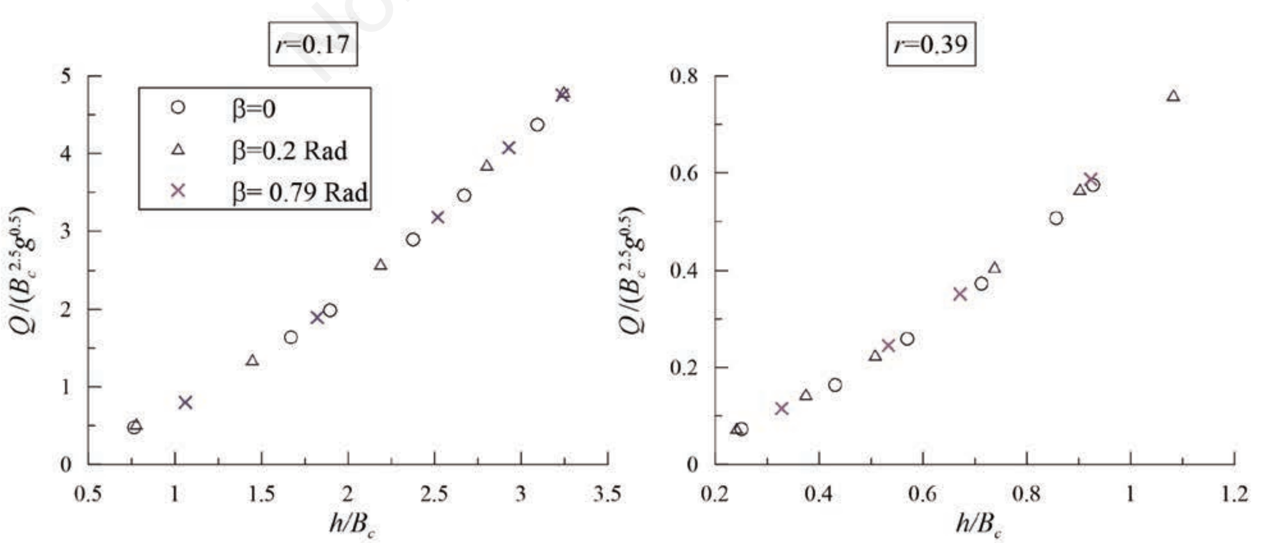

Figure 5. $Q/(B_c^{2.5}g^{0.5})$ ***versus*** h/B_c **for r=0.17 and 0.39.**

the channel width. The inlet and outlet transitions were taken as presented in Figure 1. Smaller flume width would make the portable flume lighter. The free flow condition was defined as:

$$\varphi_1\left(h,Q,B_c,B_f,g,\rho,\mu\right)=0 \tag{8}$$

in which φ_1 is a functional symbol and $B_c=B_f-b$ is the throat width.

Applying Buckingham's Theorem of dimensional analyses, the following dimensional function was obtained:

$$\frac{Q}{B_c^{5/2}\ g^{1/2}}=f_2\left(\frac{h}{B_c},r\right) \tag{9}$$

in which f_2 is a functional symbol and $r=B_c/B_f$.

Applying the incomplete self-similarity to all independent dimensionless groups, Eq. (9) was written as:

$$\frac{Q}{B_c^{5/2}\ g^{1/2}}=a_1\left(\frac{h}{B_c}\right)^{a_2}r^{a3} \tag{10}$$

Using the measured stage-discharge data of the portable flume and a least-squares technique, the coefficients a_1, a_2, and a_3 of Eq. (10) were estimated as 0.314, 1.626, and –0.697, respectively.

The comparison of Eq. (10) with the measured data points revealed that the relative error distribution was limited to the range of ±2% (Figure 8). The proposed portable flume is applicable for $0.33\leq h/B_c\leq 1.36$ with a minimum upstream depth of 5 cm. The flume is applicable for discharges of 1.9 to 18.8 *l/s*. Such a span is enough for on-farm purposes.

Field evaluation

Taking r=0.39 and B_c=15.6 cm, the validity of Eq. (10) was evaluated for the proposed portable flume field application. For this aim, the field observations were compared with the experimental stage-discharge curve obtained by Eq. (10).

As shown in Figure 9, the proposed portable TCB flume could be used effectively to obtain the flow rate through an unlined ditch. The figure also revealed that Eq. (10) was applicable to accurately determine the flow rate with a mean absolute relative error of 3.8%. The discharge varied in the range of 0.64 to 3.05 *L/s*. The maximum relative error of –6.3% was observed for Q=0.63 *L/s* located significantly out of the calibrated range of the TCB flume. Detailed field data points and the relative errors associated with Eq. (10) were listed in Table 4.

The fundamental assumptions used to develop Eq. (10) were: i) it was valid when $r\leq 0.39$ and $0\leq p/B_c\leq 1.76$; ii) neither the floor height nor an entrance ramp slope would affect the rating curve; iii) the flow must be critical in the throat. To this end, tailwater depth must be limited according to the distinguishing condition curve; iv) the flume must be installed horizontally.

Note that, in all field measurements, the flume's bed was levelled with the ditch bed (Figure 3A), *i.e.*, p/B_c=0. The acceptable accuracy of Eq. (10) revealed that the assumptions made in laboratory tests could also be extended to the field application of the portable TCB flume.

Distinguishing condition curve

Tailwater increase may affect the flow through a TCB flume. Such a flow condition is classified as a submerged regime. For a given flow rate, a unique tailwater depth h_t exists beyond which the submerged flow condition occurs. The floor height value would affect the submergence threshold of the portable TCB flume. A distinguishing condition curve, also known as the 'modular limit', is a relationship between upstream and downstream flow depths which is employed to obtain the submergence threshold (see Bos, 1989, page 29). The following functional relationship is used to describe the maximum tailwater depth for which the free flow regime occurs, h_t:

$$\frac{h_t}{B_c}=\left(\frac{Q}{B_c^{5/2}\ g^{1/2}}\right)^{\alpha}f_3\left(\frac{p}{B_c},r,\tan\beta\right) \tag{11}$$

in which α is a coefficient and f_3 is a functional symbol.

For tan β=0, the pairs ($Q/(Bc^{2.5}g^{0.5})$, h_t/B_c) are plotted in Figure 10. As shown, for a given r, the required maximum tailwater depth for which free-flow condition reveals, *i.e.*, h_t/B_c, significantly increases with higher values of p/B_c.

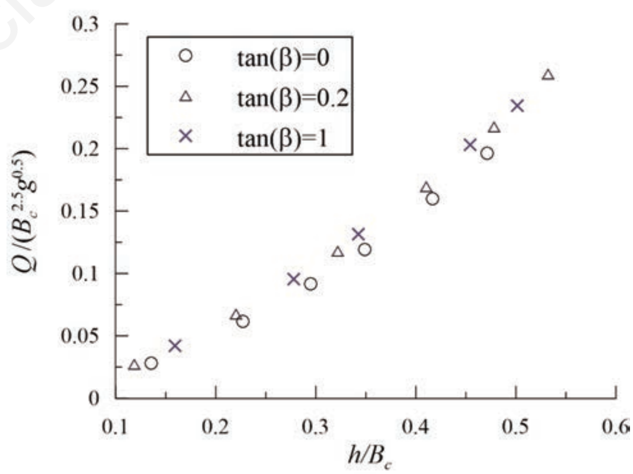

Figure 6. $Q/(B_c^{2.5}g^{0.5})$ *versus* h/B_c for different values of tan β with r=0.59 and p/B_c=0.35.

Table 4. Detailed field data and the relative errors associated with Eq. (10).

Q (L/s)	h (cm)	Error (%)
0.63	1.9	–6.3
1.6	3.45	–2.4
2.17	4.3	3.4
3.05	5.1	–2.9

For tan β=0 and applying the incomplete self-similarity condition, Eq. (11) takes the following form:

$$\frac{h_t}{B_c} = a\left(\frac{Q}{B_c^{5/2}\,g^{1/2}}\right)^l \left(\frac{p}{B_c}\right)^c r^d \quad (12)$$

in which *a, l, c,* and *d,* are coefficients to be estimated by the available measurements. Using the experimental data of this study, the obtained coefficients were listed in Table 5.

A comparison between the calculated and observed values of h_t/B_c is shown in Figure 11. Accordingly, using Eq. (12), 80% and 97% of the data points can be respectively estimated for p/B_c=0 and 0.27≤p/B_c≤1.76 with relative errors of ±10%.

Eq. (12) was used to estimate values of h_t/B_c associated with the triangular baffle flumes with an entrance ramp, *i.e.*, tan β>0. As shown in Figure 12, Eq. (12) can be applied to predict h_t/B_c accurately, even if an entrance ramp is constructed. The associated mean absolute relative error is 5.5%, and 90% of the data points

Table 5. Empirical parameters and mean absolute relative errors of Eq. (12) for p/B_c=0 and 0.27≤p/B_c≤1.76.

Parameter	*a*	*l*	*C*	*d*	MARE (%)
p/B_c=0	0.997	0.568	0	0.258	6.14
0.27≤p/B_c≤1.76	2.448	0.187	0.836	0.312	3.6

MARE, mean absolute relative errors.

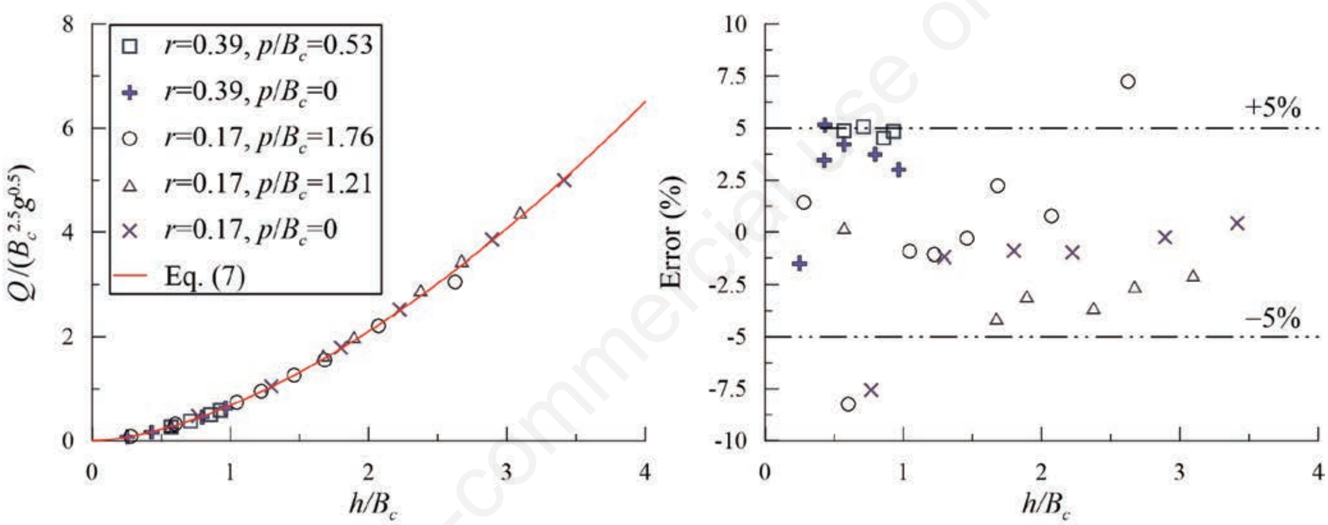

Figure 7. Stage-discharge curve and the associated relative error distribution.

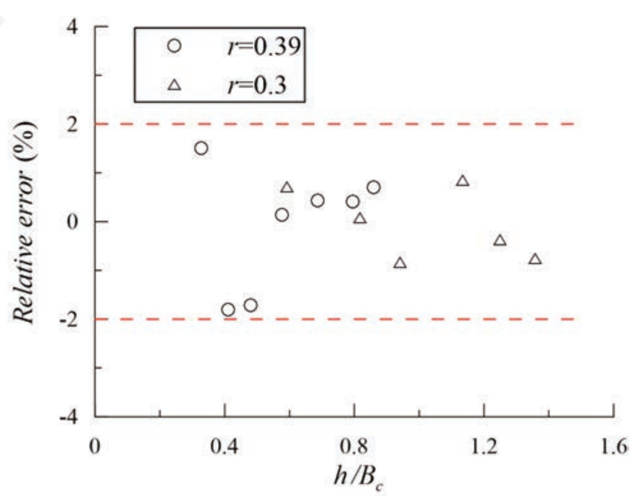

Figure 8. Relative error distribution associated with Eq. (10) and for different values of the contraction ratios, *r*.

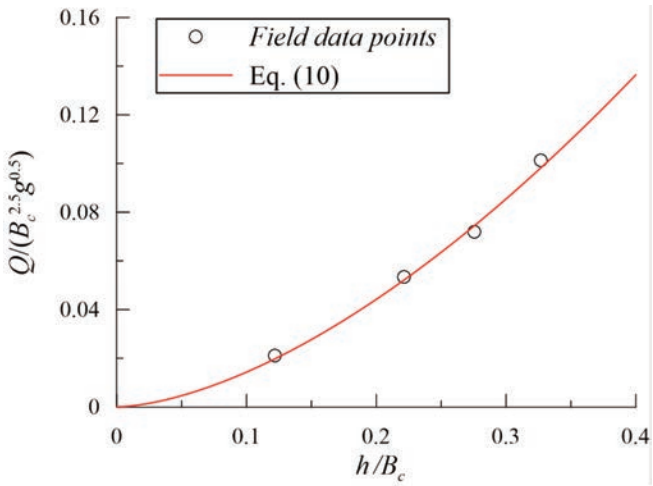

Figure 9. ***Q*/($B_c^{2.5}g^{0.5}$) in terms of *h*/B_c for field data points and the associated values obtained by Eq. (10).**

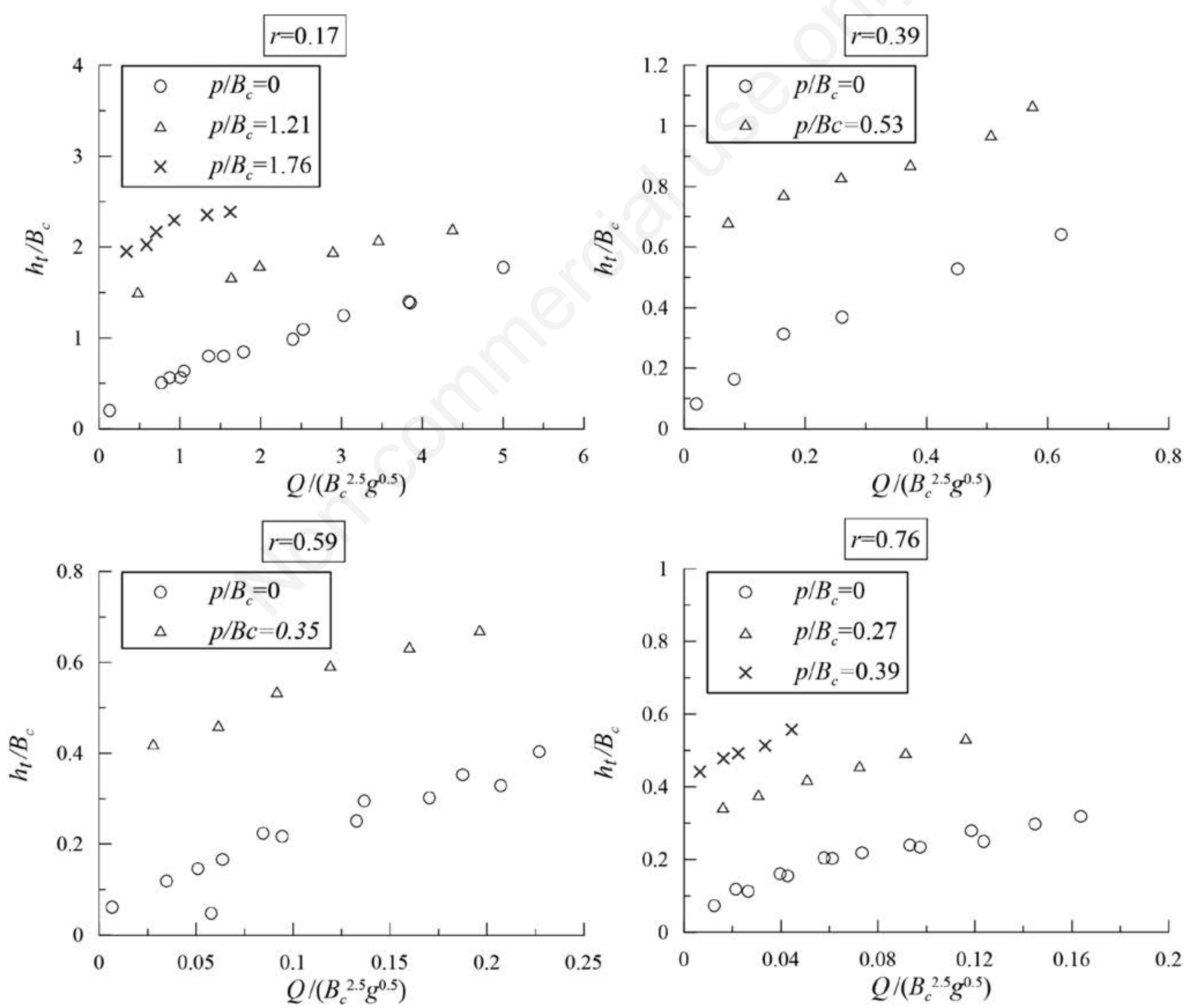

Figure 10. Values *Q*/($B_c^{2.5}g^{0.5}$) *versus* h_t/B_c for different values of r and *p*/B_c.

can be calculated with the relative errors limiting in the range of ±10%.

In other words, taking tan β>0 does not affect the maximum tailwater depth for which the free flow condition is anticipated.

Substituting $Q/[B_c^{2.5}g^{0.5}]$ from Eq. (10) into Eq. (12), the following distinguishing condition curve was obtained for the portable TCB flume when p/B_c ranges from 0.64 to 0.83:

$$\frac{h_t}{B_c}=1.971\left(\frac{h}{B_c}\right)^{0.304}\left(\frac{p}{B_c}\right)^{0.839}r^{0.182} \tag{13}$$

The relative error distribution associated with Eq. (13) was depicted *versus* h/B_c in Figure 13. As shown, the submergence threshold was estimated within a range of ±10% with a mean abso-

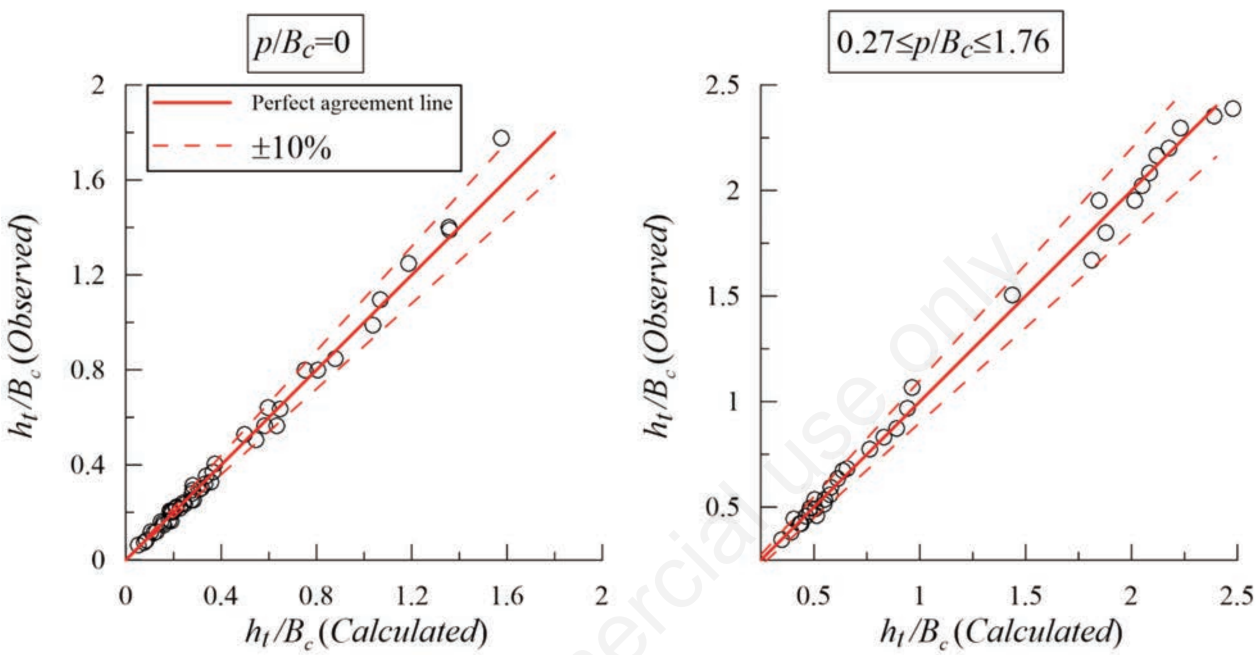

Figure 11. Calculated and observed values of h_t/B_c for p/B_c=0 and 0.27≤p/B_c≤1.76.

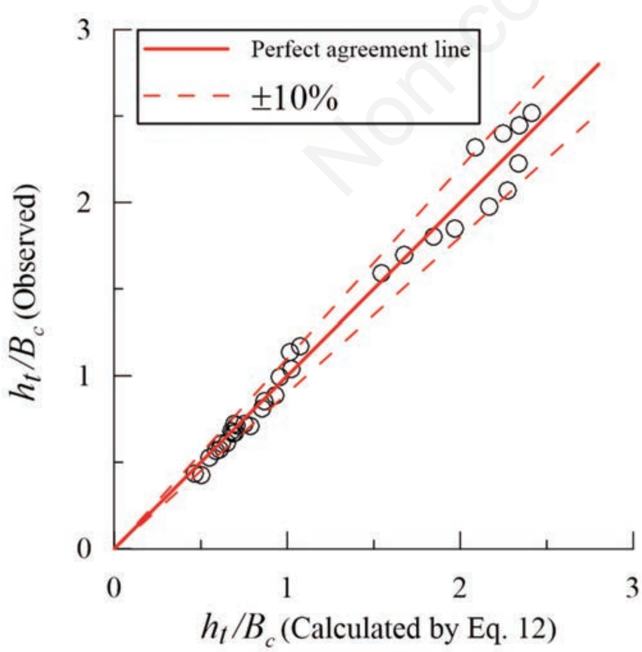

Figure 12. Calculated and observed values of h_t/B_c.

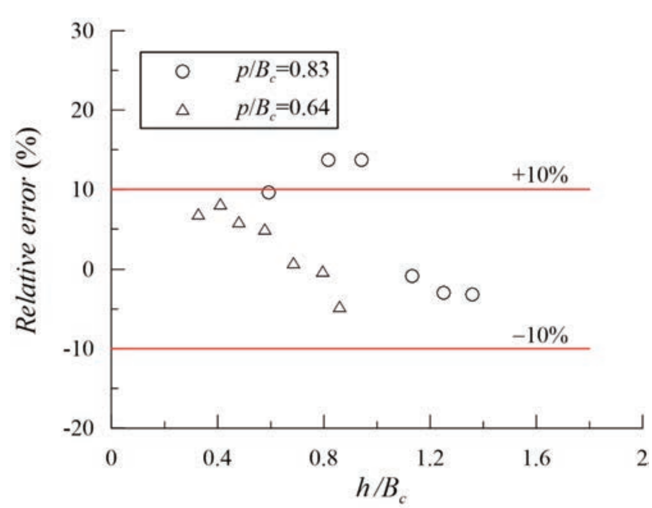

Figure 13. Relative error associated with Eq. (13) in terms of h/B_c for different values of p/B_c.

lute relative error of 5.8%.

Although the triangular shape of the central baffle minimises the flume size and weight, according to Kolavani *et al.* (2019), it might be more sensitive to submergence than the typical cases with a longer baffle length. Such a disadvantage should be considered, especially when the tailwater depth cannot be adjusted. Hence, to ensure a free flow condition, during the installation of the portable TCB flume, it is suggested to make the soil bed slightly deeper at the tailwater section to see a free overfall and a free flow condition, as shown in Figure 3B and C.

Conclusions

For the free flow hydraulic condition, the central baffle flume was investigated by both laboratory and field investigations. The laboratory tests demonstrated that contraction ratio values of less than 0.39 would ensure that the floor height ratio did not affect the flow capacity through the TCB flume. The laboratory analysis also demonstrated that an entrance ramp could only increase the discharge capacity when the contraction ratio was more significant than 0.39. According to the laboratory tests, an optimised portable flow measurement flume was proposed, and the associated stage-discharge formula was developed. Field application of the proposed portable TCB flume demonstrated that the proposed stage-discharge curve could be used accurately to determine the flow through an unlined ditch. Finally, the distinguishing condition curve and the submergence thresholds were discussed in this paper. It is strongly advised to use the proposed portable flume for free-flow conditions in which the critical flow state must occur at the throat section. Note that the proposed rating curve is only valid within the ranges of the calibrated dimensionless parameters.

Notations

a, c, d, n, l, and α = empirical coefficients;
B = the approaching channel width;
b = the baffle width;
B_c=B-b;
g = acceleration due to gravity;
h = Upstream depth;
h_{th} = the maximum permitted tailwater depth to allow the free flow condition;
H_1= total upstream head;
H_c= specific energy at the critical flow section;
L_s = Sill length;
p= floor height;
Q = discharge;
Q_V= flow rate of a venturi flume;
Q_{BR}= flow rate of a bed-rise structure;
Re= Reynolds number;
r (B_c/B)= contraction ratio;
β= entrance ramp slope angle;
f, f_1, and f_2 = functional symbols;
μ = water viscosity.

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