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Flow measurement using circular portable flume

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ABSTRACT

The circular portable flume is a simple device to measure discharge in circular drainage networks. Since the unit can be easily installed and removed, it is helpful in water distribution measurement and management. First in this paper the available studies are reviewed for highlighting the effect of both the contraction ratio and the flume slope on the stage-discharge relationship. Then the Buckingham's Theorem of the dimensional analysis and the self-similarity theory are used to deduce the stage-discharge curve of the circular flume. The new theoretical stage-discharge equation is calibrated by the literature available experimental data and those obtained in this experimental investigation for a wide range of the contraction ratios. The developed analysis suggested that the contraction ratio, which was neglected so far from the functional relationship, would significantly affect the stage-discharge curve. Finally, the effect of the flume longitudinal slope on the stage-discharge equation is tested by the experimental data obtained in this study and some other available literature experimental data.

1. Introduction

Population growth and fast industrialization make water scarcity, water quality and delivery costs urgent problems worldwide. Therefore, flow measurement devices become a key tool for a reliable management. An old management adage "You can't manage what you don't measure" could easily show the growing role of flow measurements in many water distribution systems especially irrigation networks. In this regard, simple portable flumes which are low cost and characterized by accurate discharge measurements, are really helpful for reliable flow measurements [1]. Changing in bed elevation or in channel width are generally used to construct inexpensive and simple flumes to measure the discharge in open channels [2]. Such physical changes of the channel cross section would generate critical flow near to the flume cross-section and supercritical flow at the downstream end. Consequently, the critical flow concept can be used to deduce the stage-discharge relationship of the flow measuring flumes.

Hager [2] investigated theoretically the flow through flumes with a central cylinder baffle and, using the critical flow condition, formulated the head-discharge relationships of a flume with rectangular, trapezoidal and U-shaped channel cross sections. Hager [2] also performed some experiments in a rectangular channel (0.3 m wide and approximately 5.5 m long) to investigate the flow behavior of a flume with a central cylindrical baffle.

Hager [3] proposed a mobile circular cross-section Venturi unit with a central cylindrical baffle useful for flow measuring in sewers and drainage pipes. This proposed unit can be easily installed in circular channels for short-time use. This device, as shown in Fig. 1, is a circular flume with a cylinder installed in the middle and, according to Hager [3], such flume can be used for a large discharge variation, i.e. from 1 to 150 L s^{-1}.

Employing the critical flow concept Hager [3] proposed the following theoretical stage-discharge relationship:

$$\frac{Q_T}{D^{5/2}\ g^{1/2}} = \frac{A_o^{3/2}}{(dA_o/dy)^{1/2}} \tag{1}$$

where Q_T is the theoretical discharge, D is the pipe diameter, $A_0 = A/D^2$, A is the contracted cross-sectional area, $y = h/D$ and h is the upstream flow depth.

The quantities A_o and dA_o/dy have to be computed by the following equations [3]:

$$A_o = \frac{4}{3}y^{3/2}\left(1 - \frac{1}{4}y - \frac{4}{25}y^2\right) - \left(\delta\ y - \frac{1}{12}\ \delta^3\right) \tag{2}$$

$$\frac{dA_o}{dy} = y^{1/2}\left(2 - \frac{5}{6}y - \frac{3}{4}y^2\right) - \delta \tag{3}$$

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Nomenclature

A	contracted cross-sectional area	h	upstream flow depth
A_0	A/D^2	Q_T	the theoretical discharge
a_o, a_1, b_0, b_1, b_2, m, n	empirical coefficients	r	$(D - d) / D$
d	cylinder diameter	y	h / D
D	pipe diameter	Y	H / D
D_c	$D - d$	Π_1, Π_2, Π_3	dimensionless groups
g	acceleration due to gravity	φ, φ_1, and φ_2	functional symbols
H	critical total upstream head	δ	d / D
		ε	numerical constant
		μ	water viscosity

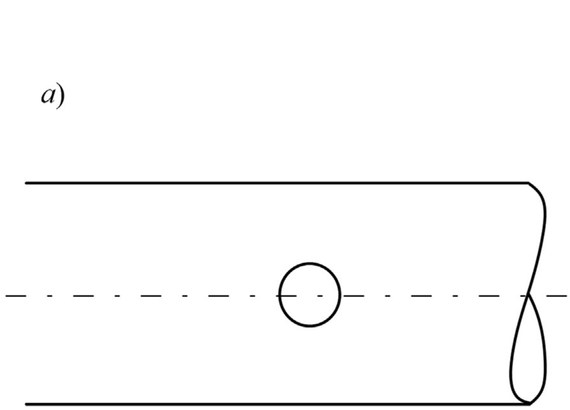

Fig. 1. Schematic view of the mobile circular flume *a*) plan view, *b*) front view.

where $\delta = d/D$ and d is the cylinder diameter (Fig. 1b).

According to Hager [3] < < *the effects of the streamline slope and curvature may become important for critical flow* > > affecting the stage-discharge equation. Therefore, the theoretical discharge values, Q_T, calculated by Eqs. (1)–(3) can be different from the corresponding measured ones. Fig. 2 shows the comparison between the values $Q_T/D^{5/2}\ g^{1/2}$ calculated by Eqs. (1)–(3) and those measured by Hager [3] for a circular flume having an internal diameter D equal to 0.488 m and a cylinder diameter d of 0.1103 m.

Fig. 2 demonstrates that the theoretical curve obtained by Eq. (1), for each h/D value, systematically overestimates the measured discharge values.

For taking into account the effect of the streamline curvature, Hager [3] proposed the following equation to calculate the discharge Q through the circular flume:

$$Q = (m + n\ \ Y)\, Q_T \tag{4}$$

where m and n are numerical constants which assume the following values:

$$m = 1 \text{ and } n = 0 \quad \text{for } Y < 0.073 \tag{5}$$

$$m = 0.985 \text{ and } n = 0.205 \quad \text{for } 0.073 < Y < 1 \tag{6}$$

and $Y = H/D$ is the critical total upstream head H normalized by the diameter D. which has to be calculated by the following relationship:

$$Y = y + \frac{1}{2}\frac{A_o}{dA_o/dy} \tag{7}$$

Samani et al. [4] investigated the effect of different flume diameters on the hydraulic characteristics of the circular flume and proposed to calculate the correction factor Q/Q_T by Eq. (4) with $m = 1.057$ and $n = 0.2266$. For high discharge values, Samani et al. [4] indicated experimentally that the effect of the sloping installation of the flume is negligible for the longitudinal slopes equal to $\pm$ 1% and $\pm$ 2%. They also indicated that the flume bed slope affects the discharge estimation significantly for the discharges of less than 0.128*l/s*.

Applying the Buckingham's Theorem of the dimensional analysis and the incomplete self-similarity theory, Ferro [5] theoretically indicated that following equation could be used as the stage-discharge relationship of the circular flume

$$\frac{Q}{D_c^{5/2} g^{1/2}} = a_o \left(\frac{h}{D_c}\right)^{a_1} \tag{8}$$

in which a_o and a_1 are two coefficients and $D_c = D - d$.

Using Samani et al. [4] data for four different values of the contraction ratio $r = (D - d) / D$ varying in a small range (0.632–0.7), Ferro [5] concluded that Eq. (8) is independent of the contraction ratio. The estimated values of $a_o = 0.4416$ and $a_1 = 2.3052$ allow to deduce the following stage-discharge relationship:

$$Q = 0.4416\ \ g^{1/2}(D - d)^{0.1948}\ \ h^{2.3052} \tag{9}$$

Ontkean and Healy [6] investigated the effect of the circular flume slope on the stage-discharge relationship of a corrugated circular flume.

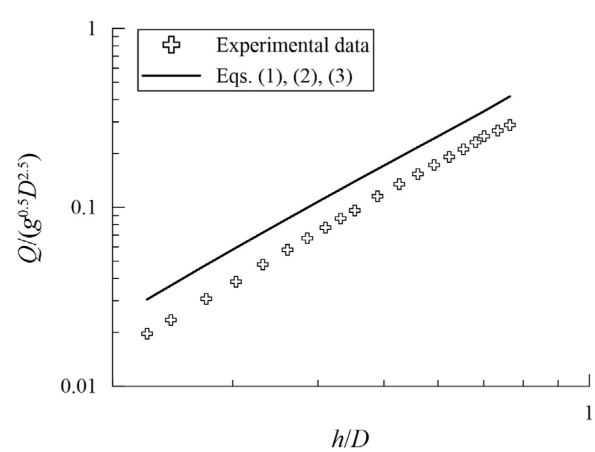

Fig. 2. Comparison between the $Q_T/D^{5/2}\ g^{1/2}$ values calculated by Eqs. (1)–(3) and those measured by Hager [3] for a circular flume of known geometric characteristics.