A Mobile Device For Flow Measurement In Canals

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Abstract

The flow pattern resulting from a circular flume immersed in a rectangular channel is investigated. The circular flume consists of two PVC pipes. The larger diameter pipe is laid horizontally and the smaller pipe is fixed vertically inside it. The presence of the vertical pipe reduces the cross section of flow inside the horizontal pipe, creating a critical-flow condition. A gage is installed at the upstream side of the vertical pipe. The depth reading on the gage is directly related to the flow-rate and hence can be used as a measure for flow-rate. This mobile apparatus can be used on both lined and unlined canals. The circular shape of the flume fits to the natural shape of a furrow, reducing the possibility of lateral flow around the flume and makes it a convenient apparatus for measurement in furrows. The results showed variations between the real and the calculated flow-rates. These variations were due to the effect of streamlines curvature and were between 0.9% to 12.1%. Calibration equation of the flow-rate correction factor was developed taking into account the streamlines curvature effect.

Keywords: water measurement, flow measurement, canal discharge.

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[illegible] PVC [illegible] 0.9 [illegible] 12.1 [illegible]

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Notation

The following symbols are used in this paper:

A = cross-sectional area of flow;
Ac = cross-sectional area of flow at critical point;
D = diameter of horizontal pipe;
d = diameter of vertical pipe;
E = upstream energy;
Ec = energy at critical flow section;
F = Froude number;
g = acceleration of gravity;
H = vertical pipe reading;
Q = flow-rate;
Qc= calculated flow-rate;
Qr = real flow-rate;
R^2 = coefficient of determination;
Y = distance from surface of water to flume floor;
2θ = the angle in radians subtended by the water surface at the center of the horizontal pipe;
ΔQ = difference between measured flow and calculated flow.

Introduction

Measuring water in open channels is an important step toward water conservation. The usual flow-rate measurement structures in open channels are based on the critical flow concept. For steady flow conditions, the critical flow condition may be achieved either by local contractions or local bottom elevation structures. The first configuration is often termed as Venturi flume, while the second structure is referred to as Weir. Withers and Vipond, [2] provided a review of numerous geometrical configurations which are normally used for permanent flow-rate recording. However, if flow-rate should be recorded at different points in a channel system (such as in irrigation or sewage canalization) only over a limited period, a mobile apparatus would be convenient. Obviously, such an instrument should not be heavy and be simply adjustable in the channel, but still permit accurate flow-rate prediction. Mobile weir installation often fails since sedimentation and solid matter in the systems considered may become significant [3].

Samani and Magallanez, [5] investigated the use of a simple flume consists of a pipe installed axially inside a trapezoidal channel. Ammari, [6] made a detailed study on the possibility of measuring flow-rate in rectangular canals using a portable cylinder.

This research was put to develop a simple, portable and low cost technique for water measurement in channels.

Experimental Work

A rectangular level (no bed slope) channel made of aluminum bed and plastic walls were used for the purpose of this research. The channel is laid in the hydraulic laboratory at the college of engineering, Univ. of Duhok. The channel is 3.5m long has a base width of 30cm and a wall height of 40cm. A 60cm part of PVC pipe (15.24cm dia.) was laid horizontally at the bed of the canal and a PVC pipe (5.72cm dia.) was fixed vertically as shown in Fig.1.

A gage was attached at the upstream face of the vertical pipe to measure the level of the water there i.e upstream of the critical flow section (Fig.2). A cutoff plastic sheet was constructed at the upstream end of the flume to avoid lateral water flow and seepage (Fig.3). Flow-rate variations were performed using a wheel operated gate valve installed on the water-supplying pipe for the channel. Real flow-rate measurement was performed using the volumetric method and replications were made three times.

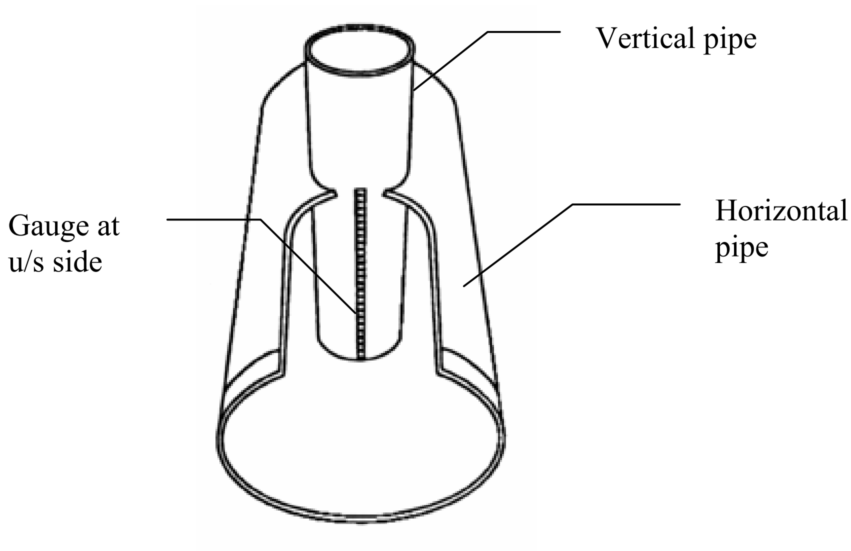

Fig.1 Components of the circular flume

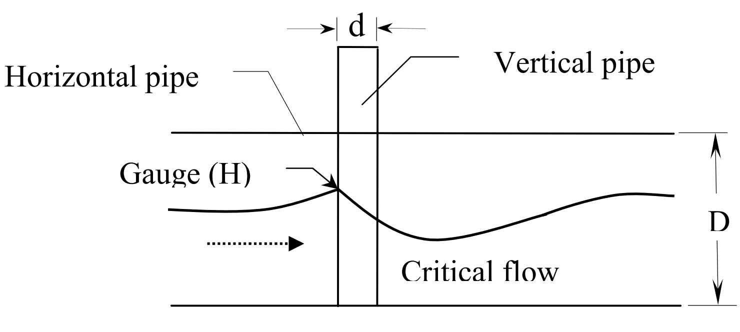

Fig.2 Water profile along flume

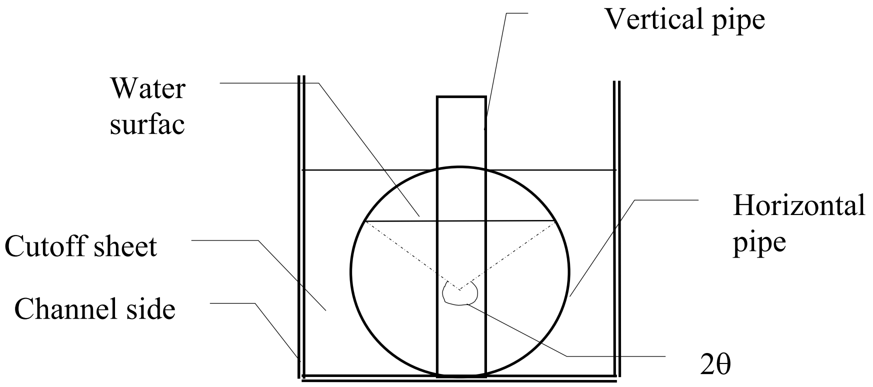

Fig.3 Cross section of flume

Governing Equations

The flow movement through the flume can be defined using the conventional energy equation and the Froude number (F) relationship [1].

Assuming a uniform velocity distribution, the energy equation upstream of the critical flow section can be written [2]:

$$E = Y_1 + \frac{Q^2}{2gA^2} \quad \text{--- (1)}$$

in which E= energy upstream of the critical flow section; Y_1= upstream water depth; Q= flow-rate; A= cross-sectional area of flow upstream of the critical flow section.

Considering a level flume, and neglecting energy loss between upstream and critical flow section, the upstream energy will be equal to the energy at the critical section, and can be described as:

$$E = Ec = Y + \frac{Q^2}{2gAc^2} \quad \text{--- (2)}$$

in which Ec= energy at the critical flow section; Y= distance from the water surface at the critical section to the flume floor; Q= flow-rate; and Ac= critical flow cross-section area.

The water will reach the critical flow at the smallest cross section [5], i.e. between the vertical pipe and the canal sides (horizontal pipe). This was also evident through the notification of hydraulic jump at the downstream portion of the horizontal pipe. Since critical flow occurs with Froude number equal to 1, the critical flow equation can be described as:

$$\frac{Q^2}{gAc^3}\left(\frac{\partial Ac}{\partial Y}\right) = F^2 = 1 \quad \text{-- (3)}$$

in which $\partial Ac/\partial Y$ represents the derivative of critical flow cross section with respect to Y.

Combining (2) and (3) results in:

$$E = Yc + \frac{Ac}{\left(\frac{2\partial Ac}{\partial Y}\right)} \text{ ---(4)}$$

When a vertical pipe of diameter d is positioned axially inside a horizontal pipe channel with internal diameter D, then the flow cross section Ac at the critical point as a function of Y is:

$$Ac = \frac{D^2}{8}(2\theta - Sin2\theta) - \frac{dD}{2}(1 - Cos\theta) \text{ ---(5)}$$

If the upstream energy can be measured, then (3) and (4) can be solved for theoretical values of Q and Y as explained later. The vertical pipe acts as a piezometer measure the sum of velocity head and the depth of the flow at the center of the canal. If the velocity distribution on a cross section of the flow is uniform, then the vertical pipe reading would be equal to upstream energy. However, due to non-uniform distribution of the velocity and streamline curvature effect, the energy at the vertical pipe should be multiplied by a correction factor to calculate the upstream energy as shown by Samani et al, [4]. This correction factor is a function of the Froude number(F).

From a practical point of view however, the depth at the vertical pipe (H) can be taken as the representative of the upstream energy (E). This is because the vertical pipe is acting as piezometer.

Equations (3) and (4) can be used to calculate theoretically, the flow-rate as a function of vertical pipe reading;

$$\frac{\partial Ac}{\partial \theta} = \frac{D^2}{4} - \frac{D^2}{8}Cos2\theta - \frac{dD}{2}Sin\theta \text{ --(6)}$$

Since; $y = \frac{D}{2}(1 - Cos\theta)$---(7)

And; $\theta = Cos^{-1}\left(1 - \frac{2y}{D}\right)$ --(8)

$$\frac{\partial \theta}{\partial y} = \frac{2}{D\sqrt{1 - \left(1 - \frac{2y}{D}\right)^2}} \text{ --(9)}$$

Also; $\frac{\partial Ac}{\partial y} = \frac{\partial Ac}{\partial \theta} \cdot \frac{\partial \theta}{\partial y}$

Then; $\frac{\partial Ac}{\partial y} = \frac{D(2 - Cos2\theta) - 4dSin\theta}{4Sin\theta}$ --(10)

A computer model was set for the calculation of Qc. This is based on substituting H measured, for E in eq.4 while expressing all parameters as function of θ using the equations 5 to 10 then solving for θ. Then using eq.3 for calculated flow-rate, Qc.

Results and Discussion

Table 1 shows the real flow-rate, Qr and the calculated flow-rate Qc based on equ. (3) and (4). H is the upstream energy reading for each flow-rate. The diameters of the pipes used for constructing the flume are 15.24cm for horizontal one and 5.72cm for vertical one.

Table 1, Measured and Calculated flow-rate

H,cm	Qr,lps	θ,rad.	A,cm^2	∂A/∂Y	Y,cm	Qc,lps	ΔQ	H/D	Qr/Qc
4.35	0.470	0.974	10.473	5.1890	3.338	0.466	0.9	0.285	1.009
4.95	0.680	1.031	13.080	5.2581	3.704	0.646	5.0	0.325	1.052
5.60	0.920	1.090	16.052	5.3333	4.096	0.872	5.2	0.367	1.055
6.10	1.140	1.133	18.384	5.3881	4.390	1.064	6.7	0.400	1.072
6.75	1.410	1.188	21.556	5.4558	4.774	1.342	4.8	0.443	1.051
7.40	1.773	1.241	24.796	5.5164	5.152	1.647	7.1	0.486	1.077
8.05	2.170	1.293	28.098	5.5693	5.527	1.977	8.9	0.528	1.098
8.50	2.420	1.328	30.418	5.6012	5.784	2.220	8.3	0.558	1.090
9.10	2.800	1.373	33.513	5.6372	6.123	2.559	8.6	0.597	1.094
9.50	3.010	1.404	35.631	5.6576	6.351	2.801	7.0	0.623	1.075
9.95	3.358	1.437	37.990	5.6763	6.604	3.078	8.3	0.653	1.091
10.30	3.633	1.463	39.840	5.6880	6.800	3.302	9.1	0.676	1.100
10.85	3.983	1.503	42.713	5.7013	7.104	3.662	8.1	0.712	1.088
11.13	4.270	1.523	44.157	5.7057	7.256	3.848	9.9	0.730	1.110
11.41	4.477	1.544	45.641	5.7086	7.412	4.042	9.7	0.749	1.108
11.60	4.716	1.557	46.620	5.7096	7.515	4.172	11.5	0.761	1.130
11.80	4.818	1.572	47.672	5.7100	7.625	4.314	10.5	0.774	1.117
12.05	5.037	1.590	48.978	5.7093	7.763	4.493	10.8	0.791	1.121
12.10	5.150	1.593	49.231	5.7091	7.789	4.528	12.1	0.794	1.137
12.20	5.210	1.600	49.739	5.7084	7.843	4.599	11.7	0.801	1.133

Theoretically, eqs. (3) and (4) can be used to calculate the flow-rate as a function of vertical pipe reading. However, since the streamlines at the critical section are not parallel, then the calculated flow-rate should be multiplied by a correction factor to account for the effect of streamline curvature. This correction factor is a function of upstream energy and the contracted channel width (Hager1986). Since the contracted flume width may equal to zero in some cases, the correction factor is taken as a function of H/D, in which H is the vertical pipe reading and D is the horizontal pipe diameter (the flume width).

A dimensionless curve is developed by plotting the relative energy versus relative flow-rate, as is shown in Fig.4.

An equation is developed based on the data in Fig.3 using the least squares technique as follows:

Qr/

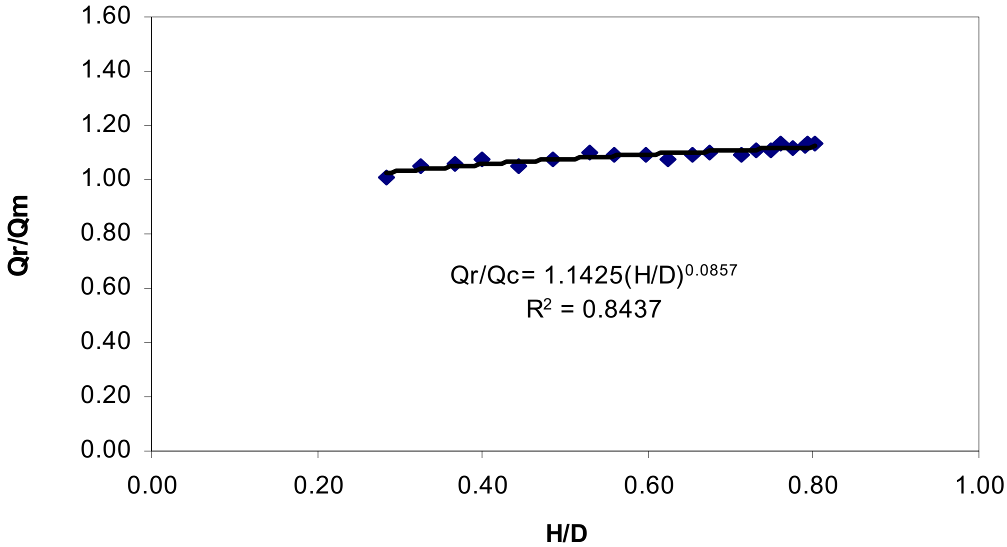

Fig.4 Relative flow-rate versus relative energy

$$\frac{Qr}{Qc} = 1.1425\left(\frac{H}{D}\right)^{0.0857} \quad R^2 = 0.8437 \text{ ---(11)}$$

Curves relating Qc (calculated flow-rate) and Qr (real flow-rate) versus H/D are also drawn as shown in Fig.5 and Fig.6 respectively. The two curves shows the increase of Qc and Qr with respect to H/D. Similarity can be noticed between the two

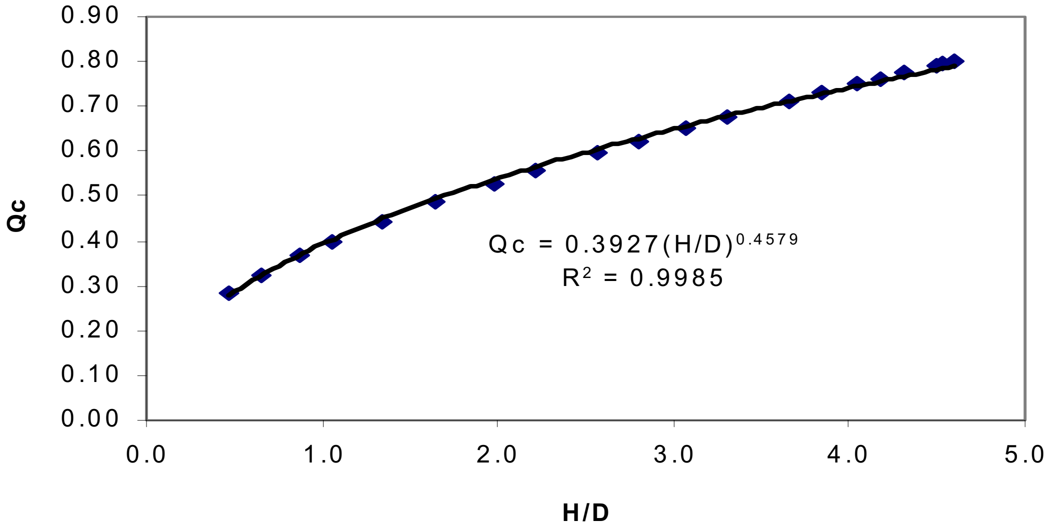

Fig.5 Calculated flow-rate versus relative energy

curves and also to a large extent between their equations. This support the use of the energy approach on the calculation of flow-rate.

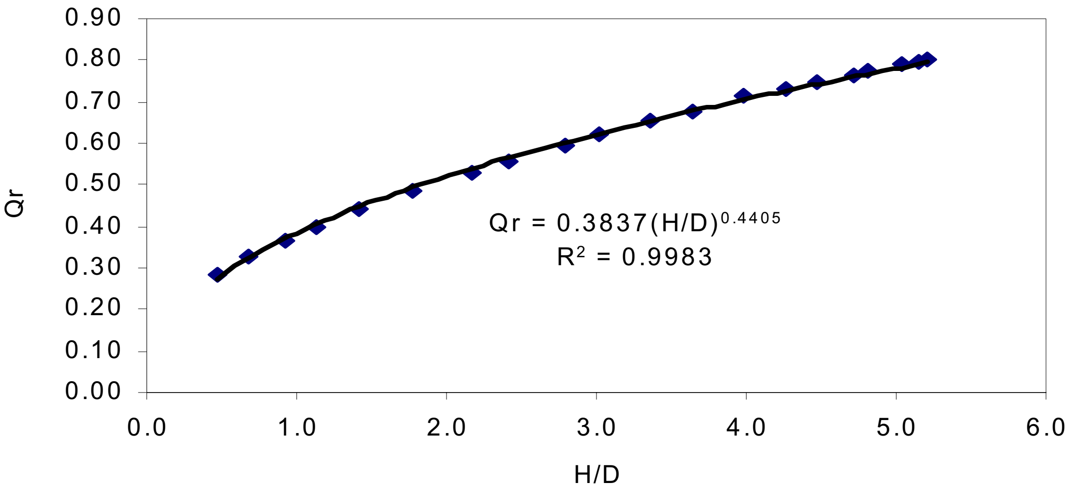

Fig.6 Real flow-rate versus relative energy

The representing equations for those curves are;

$$Qc = 0.3927\left(\frac{H}{D}\right)^{0.4579} \quad R^2 = 0.9985 \text{---} (12)$$

$$Qr = 0.3837\left(\frac{H}{D}\right)^{0.4405} \quad R^2 = 0.9983 \text{---} (13)$$

in which *Qc,Qr,H* and *D* are as early defined.

Conclusions

A simple mobile device for water flow measurement in open channels was described. The device consists of a vertical pipe positioned axially inside a larger diameter horizontal pipe. The flow using this device can be easily measured through reading of water depth on the vertical pipe.

Calibration equation of the flow-rate correction factor was developed using the least squares technique. The correction factor was developed to account for the effect of the streamline curvature.

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