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Experimental and numerical research on portable short-throat flume in the field

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ABSTRACT

The use of portable short-throat flume in the field is an emerging technique developed for water discharges measurement of inlet in the field. Based on the principle of critical flow and RNG k–ε three-dimensional turbulence model along with the TruVOF technique, experiments and corresponding simulations were performed for 16 working conditions on the 76 mm width flume with discharges up to 40.01 L/s to determine its hydraulic performance. Hydraulic performance of the flume obtained from simulation analyses were later compared with observed results based on time-averaged flow field, flow pattern, Froude number and velocity distribution. Comparison yielded a solid agreement between results from two methods with relative error below $\pm 10\%$. Regression models developed for upstream depth versus discharge under different working conditions were satisfying with the relative error of 9.16%, which met the common requirements of flow measurement in irrigation areas. Compared to the long-throat flume, head loss of portable short-throat flume in the field was significantly less. Further, head loss under the free flow condition was less than that under the submerged flow condition of portable short-throat flume with a flat base in the field.

1. Introduction

Accurate flow measurement is a fundamental component in the collection, distribution, delivery, and application of water resources [1], especially in irrigation systems. Flow-measuring structures are used for continuous measurement of discharges in open channels [2]. As mentioned by Wang [3], flumes, compared to other existing flow-measuring devices, are more suitable for flow measurement in open channels and easier to be widely applied.

Previous researches indicated that the Parshall flume has been investigated extensively based on the experimental data obtained from former researchers. In 1917, Cone [4] first reported the Venturi flume, which consisted of a converging section, a diverging section and a short throat between them. The floor was level and placed at the elevation of the bottom of the channel in which it was set. Parshall [5] developed the Improved Venturi flume, a simpler, less expensive and more accurate flume later known as the Parshall flume. Skogerboe et al. [6,7] conducted experiments on the Parshall flume under free and submerged flow conditions. Wright et al. [8] developed a numerical model to predict the effect of fluid viscosity on the depth-discharge relationship. Numerical model successfully validated through experimental data for the flume sizes studied. Cox et al. [1] determined a rating equation applicable to the large Parshall flumes with a supercritical flow. A 1.5 m Parshall flume was tested with discharges up to 0.854 m^3/s and Froude number varying from 0.67 to 1.31. Singh et al. [9] fabricated four different sizes of the small Parshall flumes in the laboratory under free flow condition. An accurate equation between discharge and upstream head valid for the different Parshall flume sizes was obtained.

On the basis of a brief review of previous studies, it would be say that there is not much work attempt for small size flume or flume set at water inlet in the field, so that water users could not get or control the discharge into the field accurately. The flume, measuring the discharge of flow into the field, needs to meet the requirements of simple structures, cheap prices, a reasonable accuracy and a low head loss [3]. The Parshall flume has lots of advantages, such as a high accuracy and low head loss. However, owing to its high price and complex structure, the Parshall flume is difficult to apply widely on water discharge measurement of water inlet in the field. Thus the Parshall flume is not the optimum choice for water discharge measurement of water inlet in the field. Originated from the Parshall flume developed by Cone [4] and Parshall [5], portable short-throat flume, consisted of a flat-bottom flume with converging, throat and diverging sections, was

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Nomenclature

The following terms are used in this paper

F_x, F_y, F_z	body forces, $F_x=0$, $F_y=0$, $F_z=-\rho g$ (N)
Fr	Froude number
H	head over the triangular weir (m)
h	depth in cross-section 3 (m)
h_u	head in upstream cross-section 1 (m)
h_w	head loss (m)
i, j	$i=1, 2, 3$; $j=1, 2, 3$
L	distance between section 1 and the control section (mm)
Q	discharge through the flume (L/s)
S	dimensionless submergence ratio, S is downstream depth in cross-section 11 divided by upstream depth in cross-Section 3
t	time (s)
$\mathbf{u}$	flow velocity vectors (m/s)
u, v, w	averaged flow velocity components in Cartesian co-ordinates x, y, and z, respectively (m/s)
ρ	density of fluid (kg/m^3)
μ	dynamic viscosity of fluid (N s/m^2)
k	turbulence kinetic energy (m^2/s^2)
ε	turbulence dissipation rate (kg m^2/s^3)
μ_{eff}	effective hydrodynamic viscous coefficient, $\mu_{eff}=\mu+\mu_t$, $\mu_t=\rho C_\mu k^2/\varepsilon$, $C_\mu=0.0845$ (N s/m^2)
α_k, α_ε	$\alpha_k=\alpha_\varepsilon=1.39$
G_k	generation item of turbulence kinetic energy k due to gradient of the averaged flow velocity, $G_k=\mu_t(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})\frac{\partial u_i}{\partial x_j}$
$C^*_{1\varepsilon}$	$C^*_{1\varepsilon}=C_{1\varepsilon}-\frac{\eta(1-\eta/\eta_0)}{1+\beta\eta^3}$, $C_{1\varepsilon}=1.42$, $\eta=(2E_{ij}\cdot E_{ij})^{1/2}\frac{k}{\varepsilon}$, $E_{ij}=\frac{1}{2}(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i})$, $\eta_0=4.377$, $\beta=0.012$
$C_{2\varepsilon}$	$C_{2\varepsilon}=1.68$

evaluated by laboratory experiments and FLOW-3D software. Portable short-throat flume was a device for flow-measurement of inlet in the field to control the discharge into the field accurately, which was not affected by type, size and bottom slope of channels.

2. Physical model and experimental setup

2.1. Physical model

Portable short-throat flume made from galvanized sheet iron, which consisted of a converging section, a throat section and a diverging section with a flat bottom, was placed at the water inlet of the field in practical application and divided into 11 measuring cross-sections (Table 1) in laboratory experiments to measure hydraulic parameters of flow. Plan-view and profile-view sketches of the flume are illustrated in Fig. 1. The flume had a length of 914 mm and a vertical height of 500 mm, while the width of the throat section was 76 mm, and the side wall was perpendicular to the bottom of the flume.

2.2. Experimental setup and methods

The experimental setup contained a pumping station, an electromagnetic flowmeter, water supply pipes, a water valve, a stabilization pond, portable short-throat flume, a backwater drainage channel and a 90° V-notch weir (Fig. 2). The flume was placed at the stabilization pond in this experimental setup similar to the actual working condition, and there was a flow condition like a water storage pit in front of the water inlet in the field. Owing that cross-section area of water inlet in the field was much larger than the entrance of the flume, water in front of the flume entrance flowed smoothly. Therefore, the cross-section area in front of the flume was much larger than the entrance area of the flume in the experimental setup, being consistent with actual flow conditions.

Table 1
Distance from first section to each measuring cross-section.

Section number	Distance from first section (mm)	Section number	Length from first section (mm)
1	0.00	7	533.00
2	114.25	8	571.00
3	228.50	9	609.00
4	342.75	10	761.50
5	457.00	11	914.00
6	495.00		

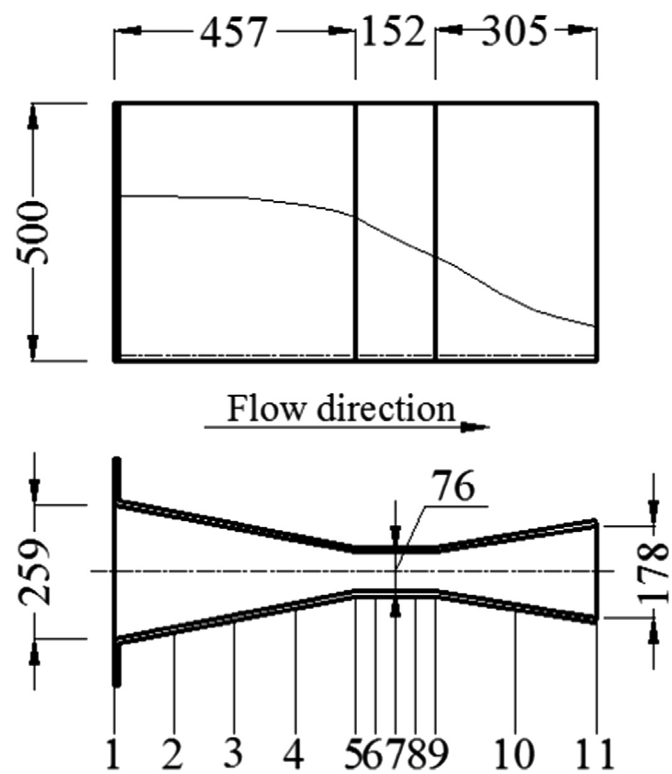

Fig. 1. Plan-view and profile-view sketches and cross sections of portable short-throat flume (Unit: mm).

Experience showed that flow capacity of the ditch in the irrigated areas ranged from approximately 10 L/s to 50 L/s [3]. The actual discharge in experiments was measured by the 90° V-notch weir using empirical Eq. (1) [10,11]. Depths of cross-sections were recorded by point gauge with resolution of 0.1 mm. 16 laboratory experiments under free flow and submerged flow conditions were conducted for the purpose of evaluating hydraulic performance of portable short-throat flume. Water was pumped into the flume, flowed through the flume and then entered the backwater drainage channel. Once flow stabilized, discharges were measured by the 90° V-notch weir [10,11], and the depths of each flume cross-section were recorded.