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RESEARCH ARTICLE

Discharge Characteristics of Parshall Flumes under Submerged Flow Condition

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Abstract

The four different sizes of Parshall flumes having throat width as 0.052 m, 0.076 m, 0.152 m and 0.229 m were tested in laboratory under submerged flow condition. Coefficient of Parshall flume (C) and exponent (n) of discharge (Q) – head relation (H) for all four different sizes of flumes were determined with the help of MATLAB Programming. It was shown that a unique relationship can be developed except for 0.229 m size flume.

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Introduction

Every day, continuing growth of population over a limited source of water, places a new demand on water resource. For conserve the water, there should be a cheap and effective water management system. The basis of a water management system is the accurate measurement of water. Accurate measurement is the way for accounting the proper use of water and accordingly supplies the available water at optimum rates to the areas where it is intended to be used. Several water measuring devices are available, such as weirs, venturi and Parshall flumes, current meter etc. Over all of these devices, flumes are most widely used and accepted devices in irrigation channels. In the irrigation system the knowledge concerning, that how much water is available in irrigation channel for supply to farmers as per their crop requirements. The volume of available water is helpful in planning for its use and distribution. The increasing utility of water over limited sources shows the value of water measurement. It makes the proper measurement of water flow very important. The measurement of flow using Parshall flume has negligible head loss and can work even under smaller head. Therefore, Parshall flume is widely used as water measuring device in open channel all over the world. The Parshall flume can operate under 0.25 times drop in water level in comparison to drop required for weir, for the same discharge under similar conditions.

Parshall flume consists of a converging section, a diverging section both are connected by the throat section as shown in Fig.1. The floor of the throat section slopes downwards and diverging section slopes upwards but below the floor level of converging section. In submerged flow condition, the two heads H_a and H_b were measured for flow measurement because downstream water depth influences the upstream water depth.

Parshall flume is a well known water measuring device. Lots of work carried out by investigators on this previously. But in submerged flow condition, there is need to further more work on small Parshall flume to develop the unified discharge relationship.

1917, Cone [3] developed Venturi flume on the Venturi principle. This was either rectangular or trapezoidal in cross section. The floor of flume was flat, converging and diverging section was connected by a short throat section. In 1928, Parshall [6] developed the improved Venturi flume, which is known as Parshall flume .This flume operates in both under free flow and submerged flow condition. This flume was dimensionally different from Cone's Venturi flume. The angle of convergence and divergence were reduced and bottom of flume was irregular .The floor in the throat section slope towards downward and floor of divergent section slope upward. Parshall demonstrated that when submergence ratio is more than 70% flow is said to be submerged flow. Discharge relation for submerged flow given by Parshall:

$$Q = 4W\, H_a^{1.522\, W^{0.026}} - \left[\left\{ \frac{H_a}{\left[\frac{1.8}{K} \right]^{1.8}} - 2.45 \right\}^{4.57-3.14K} + 0.093K \right] W^{0.815}$$

In 1965, Hyatt [4] worked on trapezoidal flume under submerged flow condition. He used the dimensional analysis for finding the parameters of submerged flow to develop the discharge relationship for trapezoidal formula under submerged flow. At the same time in 1965, Skogerboe et al [7] analyze the submerged flow condition in rectangular flume and evaluate the discharge formula for rectangular flume under submerged flow. In 1965, Skogerboe at al [8] presented a report on submerged flow in small Parshall flume (1inch, 2 inch, 3 inch). They analyzed that the analysis used for rectangular and trapezoidal flume also valid for small Parshall flume. In 1965 Skogerboe et al [9] analyze the submerged flow in 2 foot Parshall flume and analyzed that the analysis used for rectangular and trapezoidal flumes also valid for large Parshall flume. In 1966, Hyatt et al [5] prepared calibration curve for flume sizes of 6 inch, 1 foot, 4 feet, 6 feet under submerged condition. In 1967, Skogerboe et al [10] analyzed the discharge formula for free flow condition and submerged flow condition with the help of momentum theory. This study resulted with a calibration curve for the flumes having throat width ranges from 1 inch to 50 feet. In this study coefficient and exponent were determined for the different sizes of flume. Discharge formula for submerged flow is given by

$$Q = \frac{-C(H_a - H_b)^n}{\log \frac{H_b}{H_a} + 0.0044}$$

In 1994 Wright et al.[11] recalibrated the Parshall flume at low discharges and a numerical model was developed to predict the effect of fluid viscosity (in the entrance section of flume) on the depth-discharge relation. The experimental investigation indicated that the original rating equations developed by Parshall(1928) over predict the discharge at low flow rates (for flows less than about 15% of the maximum rated discharge for the flume) for all sizes of flume. In 1994, Blaisdell [2] reanalyzed the data obtain from his experiment and compare with original data of Parshall experiment. They found in their study that equation obtained from their study has similar accuracy as Parshall found in his study. In 2013, Amanda et al. [3] developed new evaluation equation precise to supercritical flow in large Parshall flumes. They recognized and distinct three zones by the convergence ratio as subcritical ($0 < Cr < 0.6$), transition ($0.6 < Cr < 1.0$) and supercritical ($Cr > 1.0$). These investigators tested a full-prototype physical model in laboratory to establish a rating equation valid to large Parshall flumes with supercritical flow

Previous studies show that lots of work has been carried out on Parshall flume But there is need to be find out discharge relationship for small Parshall flume under submerged condition.

2. MATERIAL AND METHODS

In present study, data have been collected in Fluid Mechanics Laboratory of Maulana Azad National Institute of Technology, Bhopal. In present study, the four different sizes of Parshall flumes having throat width of 0.052 m, 0.076 m, 0.152 m and 0.229 m were used. The dimensions of Parshall flumes used are given in Table 1.

These flumes were installed in a flat bed channel, having a size of 9.45 m × 0.60 m × 0.55 m. Upstream head measured at upstream and downstream by Vernier type point gauge. For the development of submergence condition in Parshall flume, downstream control gate (tail gate) was used. Actual discharges (measured discharges) were measured with the help of velocity area method. Velocity was measured by the Pitot tube. All observations are given in table (3). Under submerged flow condition discharge depends upon upstream head and head at neck of throat both.

$$Q = f(H_a, H_b, S)$$

$$Q = C(H_a - H_b)^n$$

$$Q = C H_a^n \left(1 - \frac{H_b}{H_a}\right)^n$$

$$Q = C H_a^n (1 - S)^n$$

$$Q = C Z^n \qquad (1)$$

Where Q is theoretical discharge, $Z = H_a(1-S)$, S is the submergence ratio i.e. $S = \frac{H_b}{H_a}$, H_a and H_b are the upstream and throat heads.

Equation (1) can be written as

$$Log\, Q = Log\,(C Z)^n$$

$$Log\ Q = Log\ C + n\ Log\ Z \qquad (2)$$

The discharge coefficient C and Exponent n determined through the MATLAB Programming. Accordingly corresponding equations were developed. The value of 'C' and 'n' are shown in Table 2.

3. RESULTS AND DISCUSSION

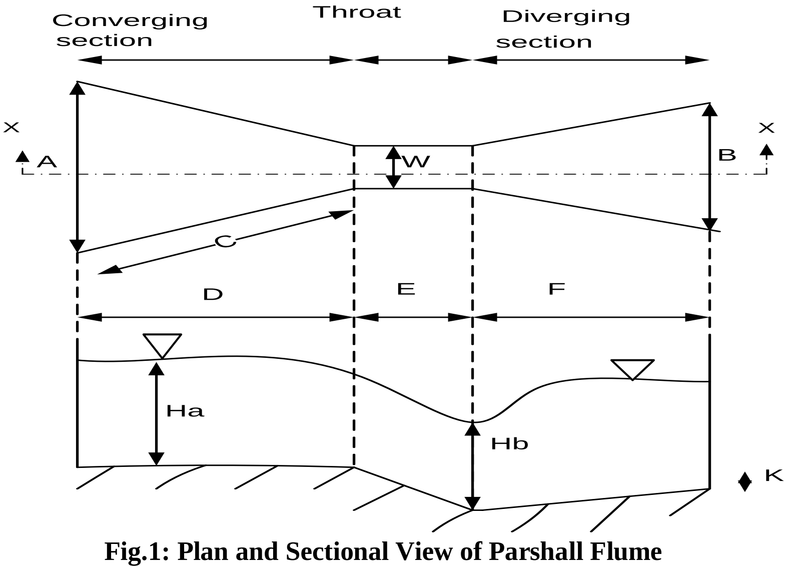

Fig.1: Plan and Sectional View of Parshall Flume

Table 1: Dimensions of Parshall flume (in m)

W	A	B	C	D	E	F
0.052	0.213	0.134	0.414	0.406	0.114	0.254
0.076	0.472	0.177	0.466	0.457	0.152	0.304

0.152	0.396	0.387	0.62	0.60	0.304	0.609
0.229	0.547	0.391	0.879	0.863	0.304	0.457

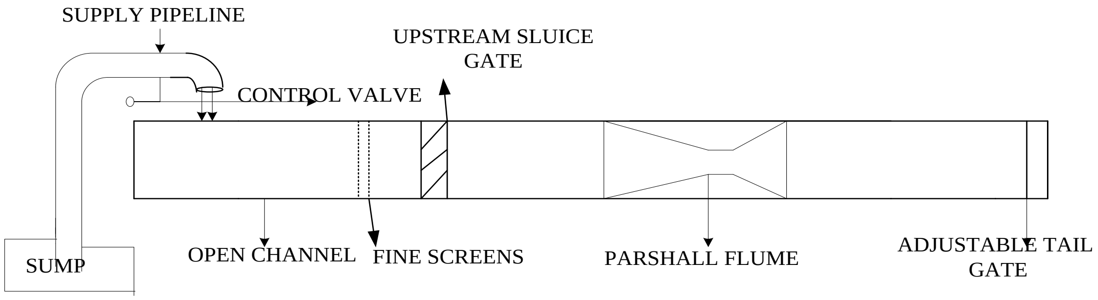

Fig.2: Schematic diagram of experimental setup

Table 2: Analysis of Experimental data

W (Width), m	C (Coefficient)	n (Exponent)	R^2
0.052	0.55	1.35	0.9931
0.076	0.803	1.502	0.978
0.152	1.172	1.63	0.997
0.229	2.155	1.57	0.995

In the laboratory, total 37 observations were taken .Observations in different sizes of flume were carried by varying the upstream head and submergence obtained by regulate the tail gate. The discharge equation for different sizes of flume obtained by MATLAB Programming using (constant from Table 2) are as follows:

For 0.052 m Flume,

$$Q_r = 0.55\,(H_a - H_b)^{1.35} \qquad (3)$$

For 0.076 m Flume ,

$$Q_r = 0.803\,(H_a - H_b)^{1.50} \qquad (4)$$

For 0.152 m Flume,

$$Q_r = 1.17\,(H_a - H_b)^{1.63} \qquad (5)$$

For 0.229 m Flume,

$$Q_r = 2.155\,(H_a - H_b)^{1.57} \qquad (6)$$

These relationships are simple and can be used for small sizes of flume. Table no2 shows that coefficient for 0.025 m, 0.076 m, 0.152 m, 0.229 m , sizes of flume varying from 0.55 to 2.155 and exponent varying from 1.35 to 1.57.

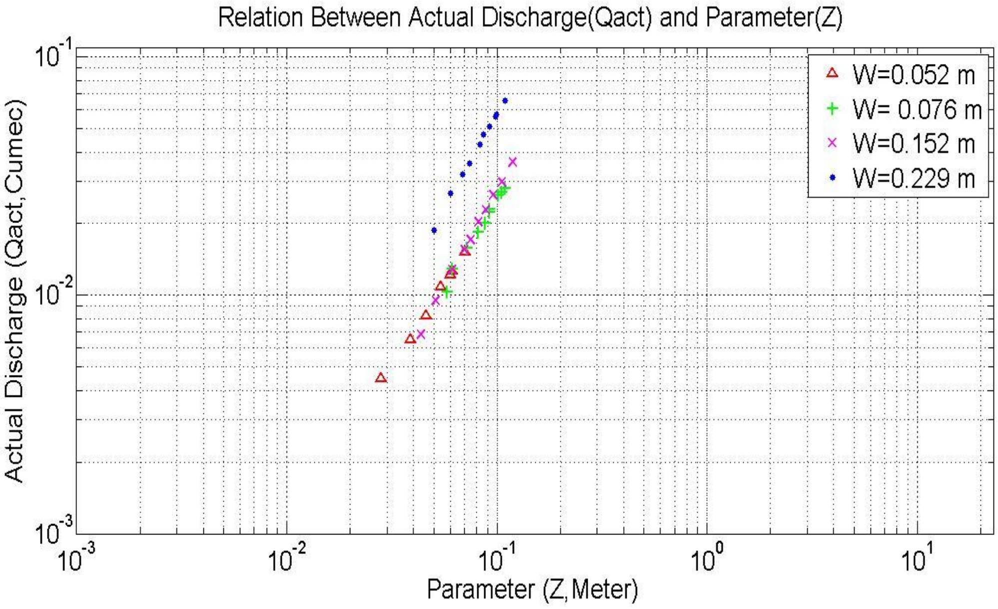

Fig.3: Variation of actual discharge (Q_{act}) with Z parameter

Fig. 3 shows the relation between actual discharge and submergence parameter Z. it clearly shows that relation for actual discharge and parameter z lies in single line except for 0.229 m throat width Parshall flume.

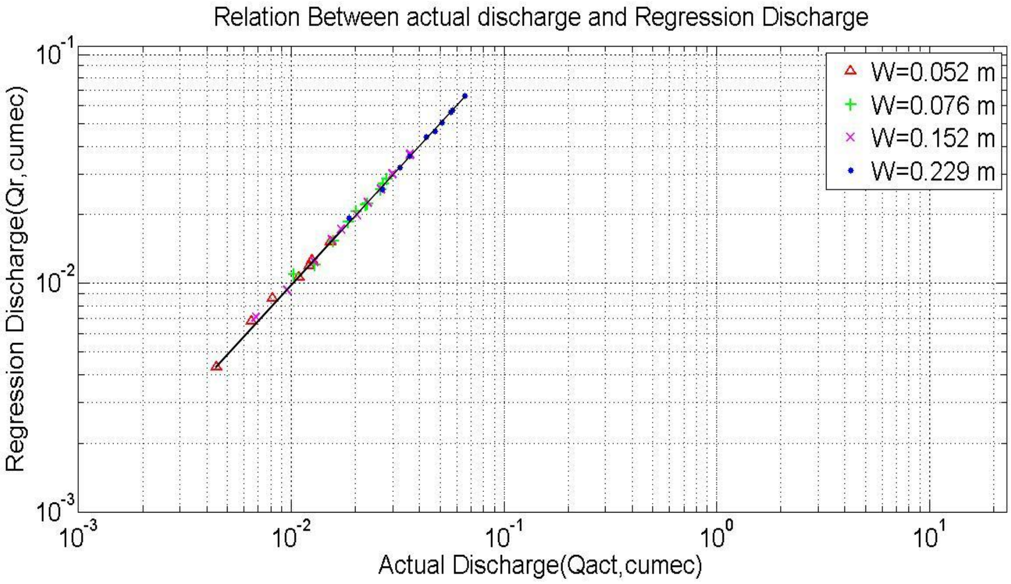

Fig.4 : Comparison between Actual and Regression Discharges

Fig.4 shows that comparison between actual discharge (measured discharge) and theoretical discharge (regression discharge). Actual discharge and theoretical discharge lies very near to each other. That means theoretical discharge calculated by above formula for each size of flume give more or less same as that measured.

Fig.3 shows that a unique equation may be develop for the all size of flume. Because variation of discharge with parameter Z, vary with approximately same exponent (n) and coefficient (C) as shown in Chart 1. So that in this study it was tried that same exponent and same coefficient can be develop for developing single equation. Keeping exponent ‘n’, constant as 1.5 (average value from Table 2) , value of ‘C; were obtained by hit and trial method. Thus the modified equations are as follows:

$$Q = C(H_a - H_b)^{1.5} \tag{7}$$

For 0.052 m Parshall Flume,

$$Qp = 0.85\ (H_a - H_b)^{1.50} \tag{8}$$

For 0.076 m Parshall Flume ,

$$Qp = 0.85\ (H_a - H_b)^{1.50} \tag{9}$$

For 0.152 m Parshall Flume,

$$Qp = 0.85(H_a - H_b)^{1.50} \tag{10}$$

For 0.229 m Parshall Flume,

$$Qp = 1.8\ (H_a - H_b)^{1.50} \tag{11}$$

This analysis developed the unique relation for 0.052 m , 0.076 m and 0.152 m flume width except 0.229 m flume width.

The single relation for 0.052 m, 0.076 m and 0.152 m flume size will be

$$Qp = 0.85\ Z^{1.50}. \tag{12}$$

For 0.229 m Parshall flume corresponding equation is,

$$Qp = 1.8\ Z^{1.50} \tag{13}$$

These equations can measure discharge with in ±8% accuracy for submerged flow along with the measure discharge are shown in Fig. 5.

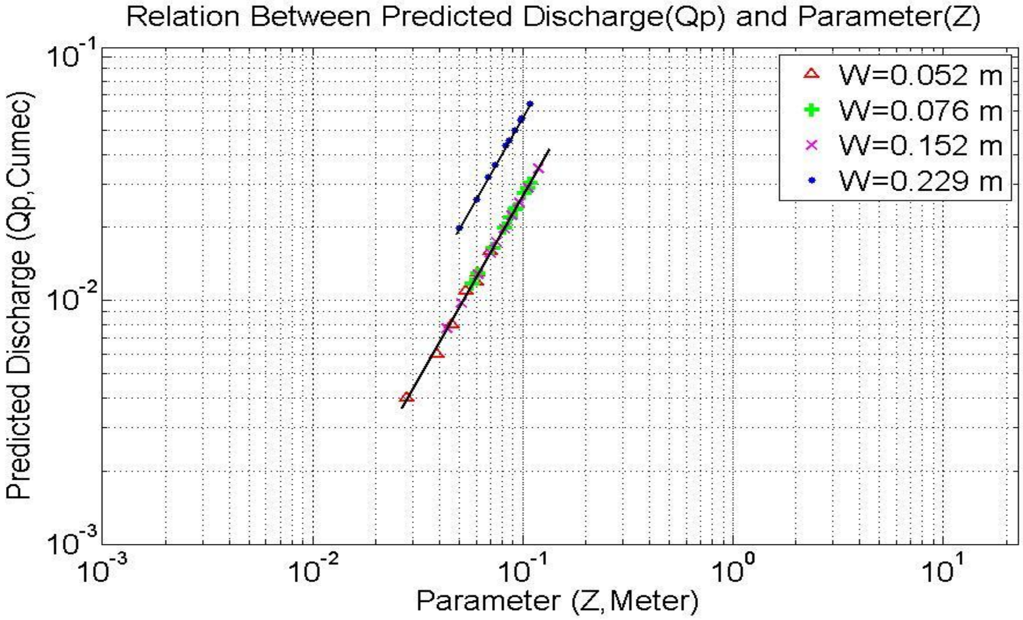

Fig. 5: Variation of predicted discharge with Z parameter

This Fig. 5 shows that the exponent (n) and coefficient(C) same for all sizes of flume except 0.229 m. For 0.229 m size only exponent is same as all other sizes of flume. It shows excellent matching.

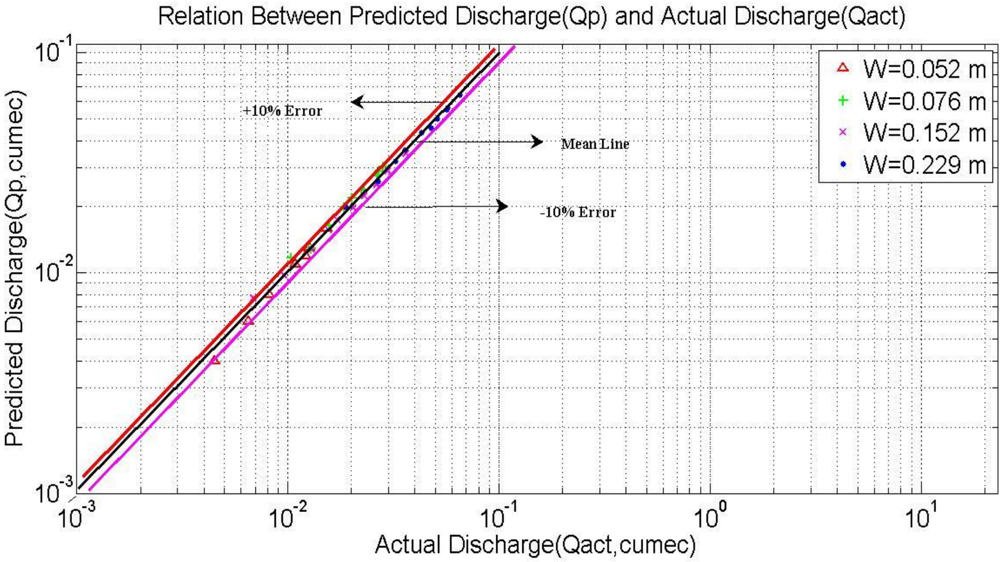

Fig.6 : Comparison between Actual and Predicted Discharges

This Fig. 6 shows that the actual discharges and predicted discharges through the modified equation 12 and equation 13 are very near to each other and lies in same line, so that predicted equation may be measure the accurate discharge may be estimate. The predicted discharges are within ±10% .

4. CONCLUSIONS

The Parshall flume, having different throat width was tested under submerged flow condition and experiments results presented in this study. In this study 37 observations were taken analyze the small sizes of flume in the laboratory. Data analyzed with the help of MATLAB Programming. Discharge and head relationship calibrated for small sizes of flume. These relationships are simple and can be use for small sizes (0.052 m, 0.076 m, 0.152 m, 0.229 m) of Parshall flumes.

From the experimental results and equations developed from programming for small sizes of flumes it is evident that equations can estimate discharge within ± 7% accuracy for submerged flow.

The common equation has been developed for 0.052 m, 0.076 m , 0.152 m ,and given below:

$$Q = 0.85(H_a - H_b)^{1.50}$$

This equation can measure discharge with in ± 8% accuracy for submerged flow.

Table 3: Observed data for submerged flow in the laboratory

Flume Size , m	Test no	H_a (meter)	H_b (meter)	S	Q_m (m^3/s)
0.052	1	0.075	0.047	0.63	0.00448
	2	0.125	0.086	0.69	0.00652
	3	0.140	0.094	0.67	0.00817
	4	0.150	0.096	0.64	0.01090
	5	0.160	0.101	0.63	0.01222
	6	0.170	0.109	0.64	0.01260
	7	0.190	0.120	0.63	0.01527
0.076	1	0.160	0.102	0.64	0.01033
	2	0.180	0.109	0.66	0.01290
	3	0.200	0.128	0.64	0.01573
	4	0.240	0.158	0.66	0.01850
	5	0.250	0.162	0.65	0.02010
	6	0.270	0.178	0.66	0.02231
	7	0.280	0.188	0.67	0.02290
	8	0.290	0.189	0.65	0.02640
	9	0.310	0.205	0.66	0.02702
	10	0.340	0.231	0.68	0.02825
0.152	1	0.140	0.097	0.69	0.00683
	2	0.170	0.119	0.70	0.00954
	3	0.180	0.119	0.66	0.01284
	4	0.200	0.130	0.65	0.01553
	5	0.220	0.145	0.66	0.01711
	6	0.240	0.158	0.66	0.02032
	7	0.260	0.172	0.66	0.02291
	8	0.300	0.204	0.68	0.02633
	9	0.330	0.224	0.68	0.02980
	10	0.350	0.231	0.66	0.03611
0.229	1	0.150	0.101	0.67	0.01900
	2	0.175	0.116	0.66	0.02672
	3	0.190	0.122	0.64	0.03234
	4	0.205	0.131	0.64	0.03594
	5	0.225	0.142	0.63	0.04304
	6	0.240	0.154	0.64	0.04750
	7	0.255	0.163	0.64	0.05110

	8	0.280	0.182	0.65	0.05640
	9	0.300	0.201	0.67	0.05725
	10	0.320	0.211	0.66	0.06542

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