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Research Article

Evaluation of Parshall flume efficiency for free flow condition open channel

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Abstract: Parshall flume provides economical and flexible water measurement capabilities for a wide variety of open channel flow situations. The advantages of this structure include minimal head loss, low construction cost, adaptability to a variety of channel types and ability to measure wide ranges of flow with custom-designed structure. In this study, head measurements of a stream behind mass communication department, Nnamdi Azikiwe, University were taken using a fabricated 6-inch Parshall flume for five days. The flow rate of the stream was computed with a Parshall flume equation. The results achieved shows that the model has good ability to estimate flow rate passing through the fabricated Parshall. When compared with the free flow calibration table for Parshall flumes, the two results were in good agreement. Flow rates computed by the fabricated 0.1524m Parshall flume have a slight difference of 0.00002m^3/s – 0.00018m^3/s, with that of the free flow calibration. The average error in the estimation of flow rate between them was 0.0032 (0.32%) with a head loss of 0.0348m.

Keywords: flume, free flow condition, open channel, flow rate, head loss, efficiency.

INTRODUCTION

The problem of determining the flow rate in open channels is one which has been considered for many years. The rapidly increasing value of water is commanding new interest in the development of new open channel flow measuring devices. Water measuring devices are important for water conservation, equitable distribution of water, determining the amount of available water, meeting legal requirements and successful management of the available supply.There are several types of flow measurement devices currently in use. Among the major types of measurement devices used in surface water (open channels) and/or closed conduits are: weirs, flumes, current meters, orifices, propeller meters, strain gage, venturi meters, paddle wheels, electromagnetic, turbine meters, ultrasonic meters, pitot tubes, elbow tab meters, vortex shedding, mass meters, and orifice plates [1]. A water measuring flume consists of an open channel structure containing a constricted section. The constriction is formed by either raising the floor or by reducing the width between the sidewalls. The discharge characteristics are the same for both types; however, the raised floor is usually classified as a weir rather than a flume. Also, unless a great care is taken in designing the raised floor section, some of the self cleaning properties may be lost [1].The most common measuring flume is the Parshall flume developed by Ralph Parshall in 1926 at Colorado State University. It is intended primarily for use in irrigation. Works on Parshall flume has been done by many researchers such as Chamberlain [2], Brouwer *et al*. [3], Skogerboe *et al*. [4], Kilpatrick, [5] and Kilpatrick *et al*. [6]. The Parshall flume combines all of the attributes necessary to the solution of water measurement problems. It is accurate, entails a minimum of head loss and is self cleaning. Again, under normal operating conditions, the discharge can be determined with an accuracy of 2 to 5 percent. The one drawback to the use of the Parshall flume, particularly in the less developed countries, is the difficulty of construction. The configuration of the throat section of a parshall flume including a sloping floor makes its construction and field installation difficult. Discharge through the flume is called “free flow”, which occurs when the water elevation downstream is not high enough to affect flow conditions upstream. Only the upstream depth needs to be measured to calculate the flow rate. Under free-flow conditions a phenomenon known as the hydraulic jump or "Standing Wave" occurs downstream from the flume. Formation of this is a certain indication of free-flow conditions. [7]. Accurate flow measurement requires a flume that causes repeatable hydraulic conditions defining a unique predesigned relation between the flow depth and the discharge at some measuring point (or points). This means that flumes must exercise hydraulic control for a large range of upstream and downstream conditions. Most importantly, where there is heavy sediment loads, flumes cannot provide hydraulic control by reducing the velocity because the sediment load will likely deposit in the flume throat and hydraulic control will be lost. Flumes for these conditions must be designed with some understanding of dynamic nature of the alluvial bed, the sediment bed, the sediment load, and hydraulic parameters [8]. The objective of this study is to measure discharge in an open channel behind mass communication department, Nnamdi Azikiwe University, Awka locally fabricated 6” Parshall flume.

Study area

Nnamdi Azikiwe University (UNIZIK) is in Awka, Anambra State Capital, Nigeria It lies within the coordinates of latitude 6°12’25’’N to 6.20694°N and longitude 7° 04’ 04’’E to 7.06778°E. It’s below 300 meters above sea level in a valley on the plains of the Mamu River. Two ridges both lying in the North-South direction, forms the major topographical features of the area. Flow rate measurement was taken from a stream within the school compound to ascertain the efficiency of the modeled parshall flume.

Fig-1: map of anambra state

MATERIALS AND METHOD

The following materials and equipments were used in the experiment;

- iroko wood (*chlorophora excelsa*) with dimensions 50mm×150mm ×3657.6mm (2-inch × 6-inch × 12-feet)
- plywood with dimensions ½-inch × 4-ft × 8-ft (12.7mm × 1219.2mm ×2438.4mm)
- plastic glass, with thickness 5mm, breadth 1219.2mm and length 2438.4mm
- top bond gum and elvostic gum used to bind the wood together
- nails and screws
- transparent plastic ruler.

Description of the lab–scale 6-inch Parshall flume

The design flume consists of a uniformly converging upstream section, a short parallel throat section (the width of which determines the flume size), and a uniformly diverging downstream section. The converging floor section was level in all direction. The floor of the throat is inclined downward with a slope of 114mm (4.49-inches) vertically, to 305mm (12.01-inches of the Parshall) horizontally. The floor of the diverging section has a slope upward of 76mm (2.99-inches) vertically to 610mm (24.02- inches) horizontally, with the downstream end of the flume 38mm (1.50- inches) lower than the crest. The size of the Parshall flume is 6-inches and the width of the throat is 152.4 mm. it has a total length of 1830mm and a height of 762.4mm. A transparent plastic ruler calibrated in centimetres and in inches was placed at 2/3 of the converging section from the crest for head measurement. the side walls were made of plastic glass and the floor of wood. The top of the side walls of the flume were also braced to support it and to keep it intact. The flume is shown in Fig. 2 while its plan and side views are shown in Fig. 3.

Fig-2: A fabricated parshall flume

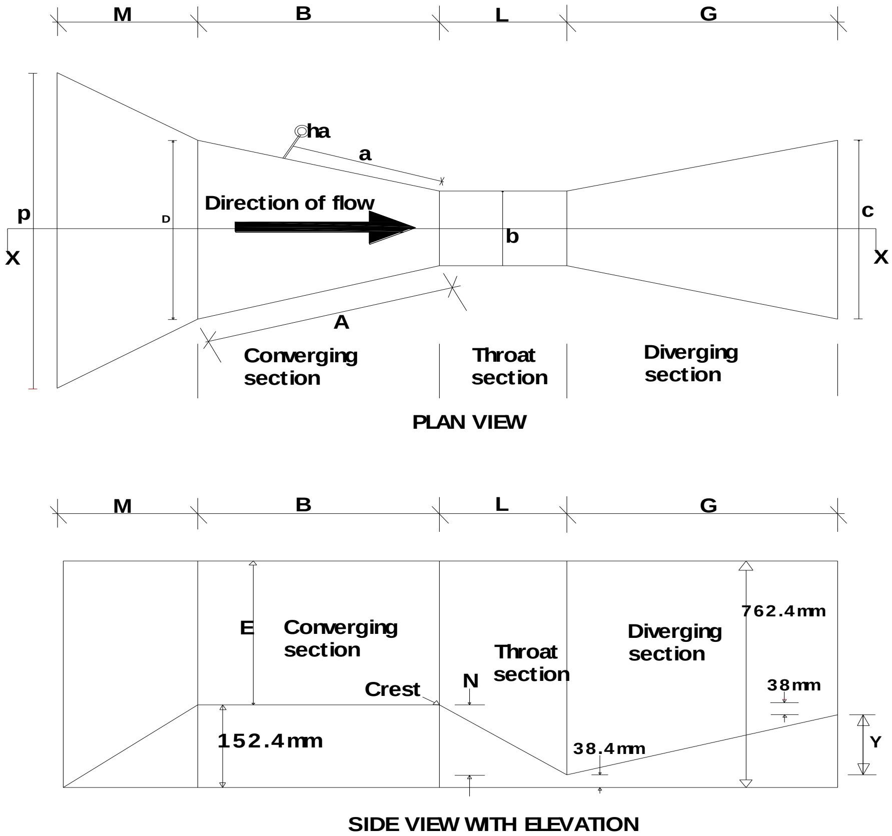

Fig-3.6: inches Parshall flume model, showing the Plan view and side view elevation

Table-1: Measurement for the Parshall flume model (All dimensions in mm)

Flume size	b	A	A	B	C	D	E	L	G
0.1524m	152.4	621	414	610	394	397	610	305	610
	H	K	M	N	P	R	X	Y	Z
	-	76	305	114	900	406	51	76	-

METHOD

The 6-inch fabricated Parshall flume was installed in a stream behind Mass Communication department, Nnamdi Azikiwe University, Awka. The flume was positioned between two hedges in order to measure the flow rate of the stream as water flows from stream side

A to stream side B. The floor of the flume was installed so that the converging entrance section is level longitudinally and laterally using a spirit level. The crest of the flume was set at the correct elevation with reference to the channel bed. The floor of the flume was placed at a depth which does not exceed the transition submergence times H_a (that is, 60% × H_a) below the high water line. Water was allowed to flow through it. Then, a phenomenon known as the hydraulic jump or "Standing Wave" occurs downstream the flume indicating a free flow condition as is shown in Fig.2. Due to this condition, only one head measurement was taken to determine discharge. The water depth upstream of the stream was measured at one third of the way into the converging section using the plastic ruler. The head measurements were taken five times for five days and the discharge rates were determined using the Parshall flume formula.

Plate2: free flow condition occurring through the parshall flume

Computation of Flow rate, using the Parshall Flume Equation

The flow rates, Q in the 6-inch Parshall flume were computed using the formula:

$Q_c = K H^n$ -------------------------equation (1)

Where;

Q_c = Computed flow rate (discharge) in m^3/s

H = Head measurement at point h_a

K = 0.3812 (a constant adopted from Table 1.0)

n = 1.58 (a constant adopted from Table 1.0)

The equation becomes:

$Q_c = 0.3812 H^{1.58}$ (m^3/s --------- equation (2)

or

$Q_c = 2.060 H^{1.58}$ (ft^3/s)--------- -----equation (3)

Table-2: Parshall flume discharge equations in free flow conditions

Flume dimensions	Discharge equations		
W	m^3/s ($K H^n$)	m^3/d ($K H^n$)	ft^3/s ($K H^n$)
1" (0.0254m)	$0.0604 H^{1.55}$	$5 215 H^{1.55}$	$0.338 H^{1.55}$
2" (0.0508m)	$0.1207 H^{1.55}$	$10 430 H^{1.55}$	$0.676 H^{1.55}$
3" (0.0762m)	$0.1765 H^{1.547}$	$15 250 H^{1.547}$	$0.992 H^{1.547}$
6" (0.1524m)	$0.3812 H^{1.58}$	$32 937 H^{1.58}$	$2.060 H^{1.58}$
9" (0.2286m)	$0.5354 H^{1.53}$	$46 258 H^{1.53}$	$3.070 H^{1.53}$
1' (0.3048m)	$0.6909 H^{1.522}$	$59 696 H^{1.522}$	$4.0 H^{1.522}$

Table-3: Computation of Flow rate for the 6-inch Parshall flume

Flume size (m)	Test No:	Upper Head, H_a (m)	Flow rate, Q (m^3/s)	Upper Head, H_a (ft)	Flow rate, Q (ft^3/s)
0.152	1	0.087	0.008	0.285	0.283
	2	0.074	0.006	0.243	0.220
	3	0.066	0.005	0.217	0.184
	4	0.042	0.003	0.188	0.148
	5	0.065	0.005	0.213	0.179

Table-4: Comparison between computed flow rate and Free Flow Calibration tables for Parshall flumes

Test No:	Computed flow rate			Free flow calibration		Difference between Q and Q_c (m^3/s)
	Upper head, H_a (m)	Flow rate, Q_c (m^3/s)		Closest upper head, H_a (m)	Flow rate, Q (m^3/s)	
1	0.087	0.00805		0.08839	0.00821	+0.00016
2	0.074	0.00622		0.07315	0.00622	+0.00000
3	0.066	0.00520		0.06706	0.00538	+0.00018
4	0.042	0.00255		0.04267	0.00255	+0.0000
5	0.065	0.00507		0.06401	0.00509	+0.00002

Determination of head loss

Taking the transition submergence of the 0.1524m Parshall flume as 60%, with a maximum discharge of $0.00805m^3/s$, which for free flow condition has a head measurement (H_a) value equal to 0.087m. The head loss through the 0.1524m Parshall flume was calculated by multiplying the maximum head measurement (H_a = 0.087m) by the transition submergence (0.60), to give a depth to flume floor of 0.0522m. Therefore, the flume crest should be set no lower than 0.0522m below the original maximum water surface (0.285ft). The head loss through the Parshall flume will be the difference between 0.087m and 0.0522m, which is 0.0348m as shown in Fig. 2.

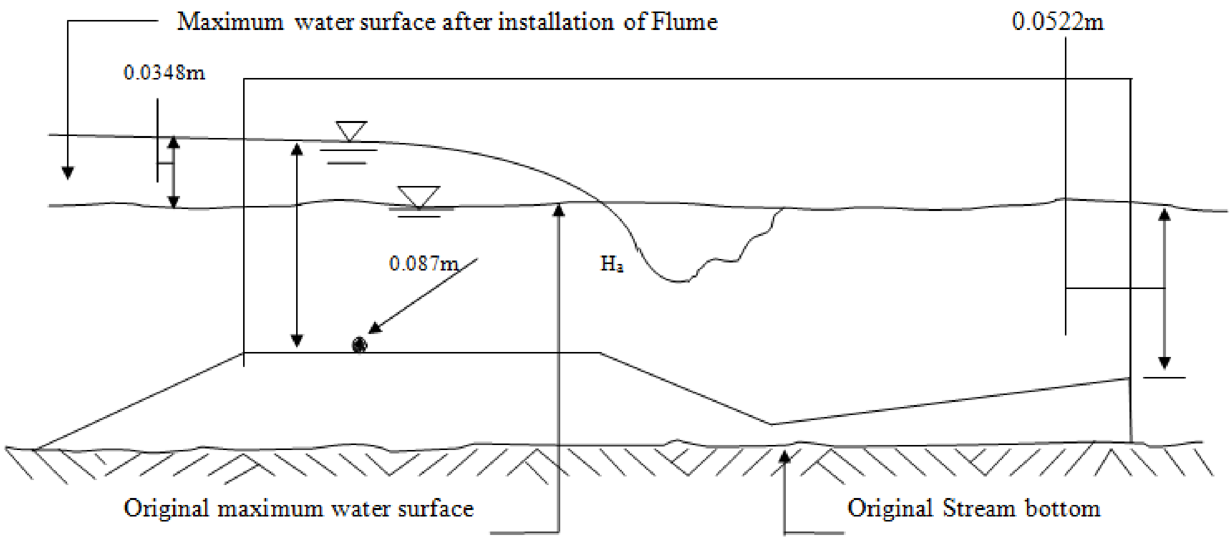

Fig- 2.0: Determination of Head loss through the 0.1524m Parshall Flume

DISCUSSION

Table 4 shows the comparison made between the flow rate computed by the fabricated 0.1524m Parshall flume formula and the free flow calibration for Parshall flumes. When compared to the free flow calibration for Parshall flumes, the free flow calibration possessed a higher accuracy, with the two results being in good agreement. Flow rates computed by the fabricated 0.1524m Parshall flume have a slight difference of $0.00002m^3/s$ – $0.00018m^3/s$, with that of the free flow calibration. The fabricated Parshall flume has an average error of 0.32%, and this shows that the flume has a good ability of estimating discharge for free flow.

CONCLUSION

Parshall flume is a well developed tool that provides economical water measurement capabilities for a wide variety of open channel flow conditions. In order to estimate the accurate flow rate of a low stream, the present study has adopted Parshall flume measurement and assessed its efficiency. The computed Flow rates by the fabricated 0.1524m Parshall flume showed similar results to the free flow calibration for Parshall Flumes. Discharge varies from $0.00002m^3/s$ to $0.00018m^3/s$ for the experiments. Based on this study, the fabricated 0.1524m Parshall flume has shown high efficiency in terms of accuracy in flow rate measurement.

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