FLOW VELOCITY MEASUREMENTS IN SMALL TO MEDIUM CHANNELS BY THRUST ROD

Sonia Zafar[1], Moien Ahsan[2], and Muhammad Masood[3]

ABSTRACT: A hinged rod of a suitable dimensions when dipped in flowing water, deflection is produced due to hydrodynamic force of flowing water and the rod attains equilibrium in its deflected state. A mathematical relationship has been developed for average velocity measurement in small to medium channels based on the density of fabricated rod material, dimensions of rod, flow depth and velocity cofficients. The water thrust was counter balanced by providing additional weight “WA” at a certain distance “S” from the hinged point. The developed theoratical relationship was verified under laboratory conditions and applied infield conditions. Four rodswere made of Aluminium and seasoned wood of varies dimensions. The calculated velocity was compared with measured velocity and Aluminium rod of width twice the thickness gave more accurate estimation of velocity. The perecntage error in Laboratory and field condition was less than±3% and ±5 % respectively.

Index terms; Velocity Measurement, Theoratical Relationship, Additional Weight, Thrust Rod, Mathematical Model, Open channels, Discharge measurement

◆

---

[1] Deputy District Officer, OFWM Directorate, Punjab, Pakistan, PH: +92 334 4415152, E.mail: sonia_zafar_74@yahoo.com.

[2] PhD Water Resource Engineering Scholar, Centre of Excellence in Water Resource Engineering, University of Engineering and Technology, Lahore Pakistan PH: +92 334 4415225 E:mail: moienuet@gmail.com.

[3] Assistant Professor, Centre of Excellence in Water Resource Engineering, University of Engineering and Technology, Lahore Pakistan PH: +92 333 4781224 E:mail:chmasoud@gmail.com.

1. INTRODUCTION

Accurate measurement of water permit more efficient use of this valuable natural resource. Systematic water measurements properly recorded, interpreted and used constitute the foundation upon which increasing efficiency of water conveyance application and use must be based.Different techniques are used for flow measurement in open channel e.g.Weirs, Flumes, Current meter, Velocity rod, Magnetic flowmeter, Ultrasonic flowmeter. All these techniques require perfect installation of certain fixtures in channel before flow measurements.Chemical method is also used for finding out discharge and then velocity of the flowing water.

Deflecting velocity rod is also used for flow measurements in small and medium channels. This technique involves immersing a hinged rod in flowing water. The velocity currents tend to produce deflection under the hydrodynamic force of flowing water. The rod attains equilibrium at the deflected position with respect to flow depth and flow velocity.

A single velocity rod can be used for measuring velocity under varying flowconditions and in channel of different dimensions without installation of any hydraulic structure. Velocity is measured by measuring the corresponding flow depth and angle of deflection. Flow measurements with velocity rod may contain ±10% error due to the imperfection of the experimental setup.

An easy and quick technique is required for flow measurements in small and medium channels. A simple technique can be developed by immersing a rod in flowing water provided by counter balancing moment arm at a certain distance "s" (Fig. 1.1).It is noted that the force required to keep the rod in its vertical position increase with an increase in submerged depth.

The purpose of the study was to develop a theoretical relationship for velocitymeasurements by a thrust rod and to verify the theoretical relationship developed under laboratory and field conditions for small and medium channels. In this study the flow velocity is obtained by using flow mate,V notch weir, flume and orifice plate. The velocity measured is compared with the velocity calculated from developed theoretical relation using a thrust rod for a given depth and discharge. Discharge can be easily obtained once the velocity is determined by the thrust rod. Some limitations and assumptions for the study are: The channel is prismatic, channel bottom slope is small, flow is steady uniform. flow shuould be subcritical, Pressure distribution is hydrostatic in the channel section.

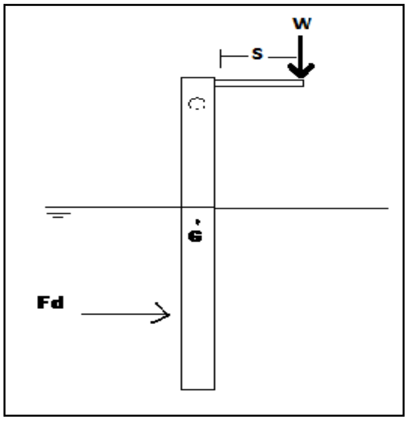

Figure 1: Deflecting Velocity rod

2. BACKGROUND

Bengtson [3] used the Manning equation for open channel flow velocity calculations. It can be used for flow rate and flow velocity calculations in manmade open channels, and for river discharge and river flow velocity in terms of the slope, size and shape and roughness characteristics of natural channels.Wilkerson. G V. and Mcgahan J L. [7]developed two models for predicting the depth-averaged velocity distributions in straight trapezoidal channels. The second model yields good results than the first model. Fonstad [4] developed a new tool for indirect stream velocity estimation. the transparent velocity-head rod (TVHR) is typically precise within ±5%.USBR(6) suggested the Kindsvater-shen equation for flow measurements in open channels using v-notch weir. Awan (2) studied thatin order to obtain a physical picture of velocity distribution in a channel the velocity contours called isovels are drawn. Acker (1) explained the main techniques available for flow velocity measurements in open channels e.g Hydraulic Structures e.g. Weirs, Orifices and Flumes, Velocity-Area Method, Dilution method and Slope-hydraulic radius area method.

3. METHODOLOGY

1.1. Development of Mathematical Model

Mathematical model is developed for velocity measurements in small and medium channels. From this mathematical model flow velocity can be easily computed by measuring additional weight added to the immered rod.

A theoretical relationship between the average flow velocity and the additional weight “W_A” added to the thrust rod is developed. Let a hollow rectangular rod of length L, mass M, cross-sectional Area A, and additional weight W_A added to the rod at a certain distance S, be dipped in water. The distance “s” is adjusted to counterbalance the water thrust by adding weight to the rod. Change in velocity causes change in momentum of flowing water. Water is displaced by the weight of rod and in reaction water also exerts an equal force on the rod but in opposite direction. Alternatively, the water thrust was balanced by the additional weight W_A provided at a certain distance “S” to the thrust rod. The rod attains equilibrium in vertical direction (Perpendicular to flow direction). To show the effect of force applied by the water currents on the immersed rod, consider a small length of rod dL at which water is striking with velocity “V” as shown in Figure 2.

Face Area (da) of the rod is given by

$$d_a = Wd_L \qquad (1)$$

W = width of thrust rod

d_L = Length of rod section.

Rate of mass of water (*dm*) striking at da is given by

$$dm = \rho da V \qquad (2)$$

ρ = Density of water

V = Velocity of water striking the rod.

Force exerted by water on the thrust rod in the direction of flow
is given by

dM= Rate of change of momentum in the direction of flow.

$$dM = \frac{\text{Initial momentum} - \text{Final momentum}}{\text{Time}}$$

$$dM = \frac{\text{Mass}}{\text{Time}}[\text{initial velocity} - \text{final velocity}]$$

After striking with the thrust rod final velocity becomes Zero

$$dM = \rho \text{ da } V[V - 0]$$

$$dM = \rho da V^2 \qquad (3)$$

Force exerted by flowing water on da is

$$dF = \rho da V^2 \qquad (4)$$

As, Width of the rod is constant

So,

$$dF = \rho wdL \quad V^2 \qquad (5)$$

Integrating above equation over the submerged length of rod to give the total force exerted by the flowing water on immersed rod due to change in momentum of water

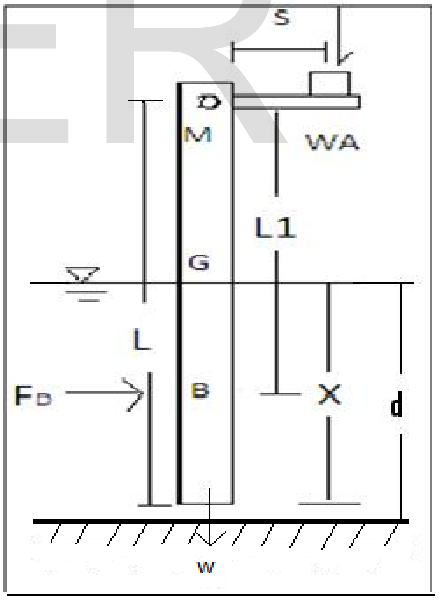

Figure 2: Thrust Rod

$$F = \int df = \int_0^X \rho w V^2 \, dL \qquad (6)$$

$$F = \rho \text{ w } V^2 X \qquad (7)$$

X = Submerged length of thrust rod.

This force produces a moment in the immersed rod about the hinge, this moment is opposed by the moment produced by the weight of rod itself and theadditional weight W_A added to the thrust rod.As, the rod is in equilibrium in its vertical direction;

$$\sum Fy = 0$$

$$\sum M = 0 \qquad (8)$$

$$F_D \times L_1 = W_A \times S \qquad (9)$$

From figure 3

$$L_1 = L - \frac{X}{2} \qquad (10)$$

Using values from eq. (7) and (10) in eq. (9)

$$(\varrho\, w\, V^2\, X) \times (L - \frac{X}{2}) = W_A \times S \quad (11)$$

$$(\varrho\, w\, V^2\, X) \times \frac{2L - X}{2} = W_A \times S \qquad (12)$$

$$V^2 = \frac{2W_A \times S}{(2L - X)\rho\, w\, X} \qquad (13)$$

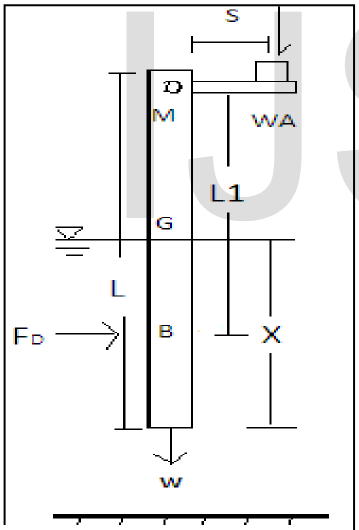

Figure 3: Thrust rod in equilibrium

$$V = \sqrt{\frac{2W_A \times S}{(2L - X)\, \rho\, w\, X}} \qquad (14)$$

$$V = \sqrt{\frac{2W_A(gm) \times S(\ cm)}{(2L\ (cm) - X\ (cm))\rho\left(\frac{g}{cm3}\right) w(cm)\ X(cm)}} \quad (15)$$

The average flow velocity in the channel section is related to the flow velocity in the middle section as,

$$V_A = CV \qquad (16)$$

Therefore,

$$V_A = C\sqrt{\frac{2W_A \times S}{(2L - X)\, \rho\, w\, X}} \qquad (17)$$

V_A=Average calculated velocity, (cm/s)

C = Coefficient of velocity

W_A=Additional weight attached to the thrust rod(gm)

W=Width of thrust rod, (cm)

S=Distance from the hinged point, (cm)

X= Submerged depth, (cm)

L=Length of rod, (cm)

1.2. Experimental Setup and Laboratory Setting

Thrust rod of suitable dimensions was developed. Weight "W_A" required to counter balance the water thrust was noted on a glass sided tilting flume in hydraulic laboratory of Centre of Excellence in Water resource Engineering, UET Lahore for different values of discharge and flow depths. Flow velocity was calculated using the developed relation (17). To check the accuracy of results, the flow velocity in channel section was also measured on glass sided tilting flume. Discharge was calculated using an orifice plate provided in the outlet pipe of glass sided tilting flume using relation.

$$Q = A \times V \qquad (18)$$

A= Area of channel, cm^2

Q= Flow rate, Cusecs

V= Flow velocity, cm/s

Further, the developed relation (17) was verified under field conditions for small and medium channels. The laboratory measurements were conducted on S6 glass sided tilting flume in the Hydraulic laboratory of the Centre of Excellence in water Resource Engineering. The S6 flume has rectangular glass channel of 30cm wide and 53cm high. The flume channel was provided with the accessories i.e orifice, Flow control valve, Jack assembly, Overshoot weir gate.

Wooden and Aluminium rods of suitable length, shape, thickness and width were selected for experiment. Four rods were made water proof by coating with synthetic material i.e. silicon, so that no change in weight of rod occur when dipped in water. Graduated scale was attached to all the rods.

Table 1: Characteristics of Rod

Rod No.	Material	Shape	Mass, (Gm)	Width, (cm)	Thickness, (cm)	Density(g/cm^3)
1	W	S	690	5.08	5.08	0.38
2	W	R	600	5.08	3.14	0.38
3	A	S	476	5.08	5.08	2.7
4	A	R	260	5.08	2.14	2.7
Rod	Mate	Shape	Mass, (Gm)	Width,	Thickness,	Density(g

No.	rial			(cm)	(cm)	/cm3)
1	W	S	690	5.08	5.08	0.38
2	W	R	600	5.08	3.14	0.38
3	A	S	476	5.08	5.08	2.7
4	A	R	260	5.08	2.14	2.7

Note: W=Wood, A=Aluminium,
S=Square, R=Rectangular

Rod supporting assembly consists of two wooden blocks 20cm in length having holes at a distance of 2.1 cm to hold thrust rod on flume channel in Hydraulic Laboratory of Centre of Excellence in Water Resource Engineering, UET, Lahore. These holes were made frictionless so that rod can move freely under the action of water thrust. A plastic rod was passed through thrust rod. Two wooden blocks were placed on the edges of flume channel to hold the rod on the channel. A graduated scale was attached to the flume channel to measure the flow depth accurately during flow measurements under laboratory conditions. Thrust rod with supporting assembly and experimental set up under laboratory conditions are shown in figure 4, and 5 respectively.

Figure 4: Experimental setup (Left) and Thrust rod in balance condition (right).

Four rods (Rod 1, Rod 2, Rod 3 & Rod 4) out of which Rod 1 and 2 made of wood Rod 3 and 4 made of Aluminium were used to calculate the velocity by using theoretical equation (17) by measuring the additional weight added to the rod in order to counter balance the water thrust at a given flow depth and discharge.Velocity was also measured using current meter at different discharges. The velocity measured at different depth by using thrust rods and current meter is as shown in the table 2 and figure 7.

Velocity was calculated at different dischrge e.g 31.21 L/S, 35.67 L/S and for 41.32 L/S and compared with current meter velocity at different depths.

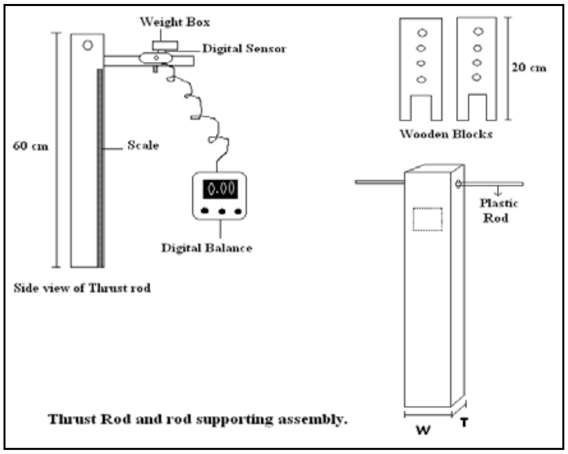

Figure 5: Thrust rod and supporting assembly
.

Flow Depth(cm)	Thrust Rods Velocity(cm/s)				Vc(cm/s)
	Rod 1	Rod 2	Rod 3	Rod 4	
26	13	20	25	36	35
28	12	19	23	33	32
30	12	17	20	31	30
32	11	14	19	29	28
34	10	13	16	26	27
36	---	---	13	24	25
38	---	---	10	23	24

Note: Vc=Current Meter Velocity,

---=Undefined

Velocities calculated using orifice plate, thrust rod and current meter was compared, each calibrated against same values of discharge and flow depths. The coefficient C_v was determined by drawing a best fit line between Rod velocity,V_R and current meter velocity, V_C.

$$\mathbf{C_V} = V_C / V_R \qquad (19)$$

Where,

C_V = Velocity coefficient

V_R = Rod velocity

V_C= Velocity measured using current meter

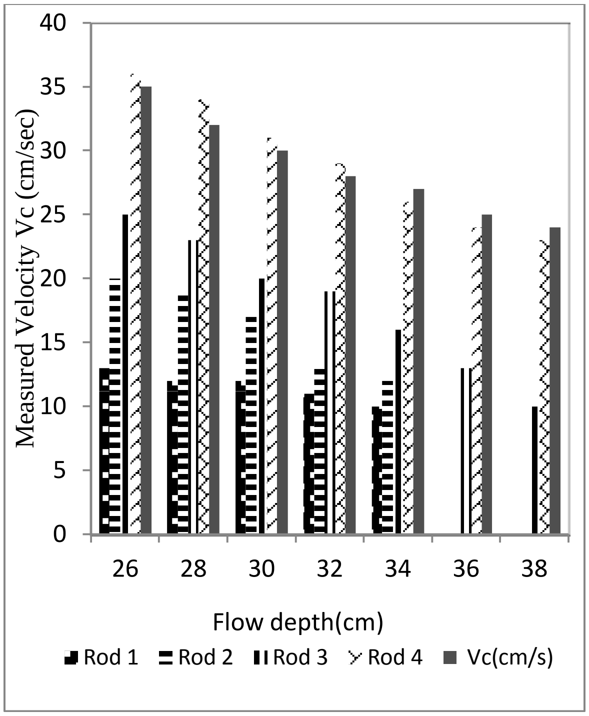

Figure 6: Current meter and thrust rod velocity for discharge

Velocity coefficient accounts for the turbulance around the thrust rod and other errors not satisfying the assumptions considered for developing the theoretical equation (17).

1.3. Velocity Measurements Under Field Conditions

For flow velocity measurements under field conditions five small and medium channels feeded by Lahore canals were selected. Arrangement of the thrust rod under field conditions consists of a wooden plank placed across banks of channel to facilitate field measurements. For flow velocity measurements the rod and supporting assembly was placed in straight reach away from outlet or culvert to maintain the conditions of steady uniform flow.Velocity was calculated using thrust Rod 4(Aluminium) and equation (17). Also the velocity was calculated using currentmeter at 0.6 of the flow depth. Both the velocities were compared to check the accuracy of result.

Based on the characteristics and fairly accurate results obtained under laboratory conditions for given depth and discharge, Rod 4 was usedfor flow velocity measurements under field conditions. For same discharge velocity obtained using equation (17) was compared with velocity measured using current meter. For this purpose five lined channels were selected. It was found that for channel 1, 4 and 5 the current meter velocities (V_C) lies very close to that calculated usingtheoretical equation 3.17. The calculated percentage error for field channels was approximately ± 4% except for channel 2 &3 i.e. ± 5%. This error was due to the excessive submergence of rod i.e. 68% which was more than the upper limit of submergence for Rod 4 or may be due to some experimental error while taking readings in channel 3. Because the conditions on which the thrust rod was developed changed due to higher discharge and flow depth. A sudden hump in the flow velocity was observed for channel 3 as shown infigure 4.10.

Table 2: Thrust Rod velocity and measured velocity in field

Sr.No	Q,	D	V_R	V_C	%
1	11.10	38	22	23	4
2	5.9	31	20	21	5
3	21.17	42	36	38	5
4	28.25	34	24	25	4
5	12.50	31	23	24	4

Note: Q= Designed Discharge (Cusecs), D=Flow Depth (cm), V_R=Thrust Rod Velocity (cm/s), Vc=Current Meter Velocity (cm/s), %=Percentage Error.

C_V=Velocity coefficient i.e. 57

$\%Error=(V_R-V_C)/V_C*100$

V_R= Thrust rod velocity (cm/s)

V_C= measured velocity using current meter (cm/s)

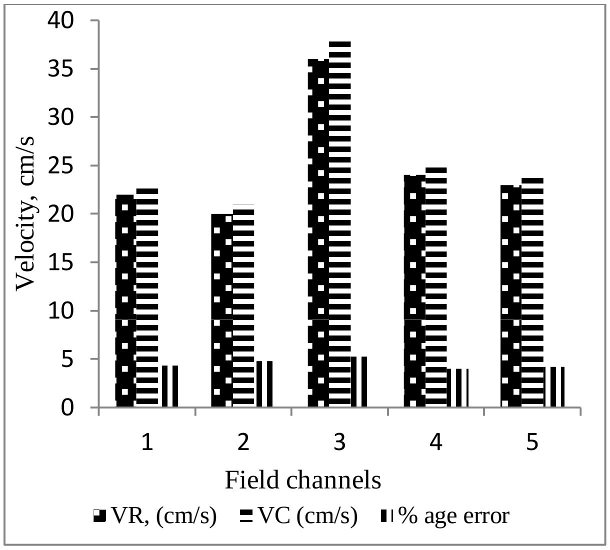

Figure 7: Thrust rod and Current meter velocity for field channels

4. CONNCLUSIONS AND RECOMMENDATIONS

The technique of thrust rod can be used successfully to estimate the average flow velocity in small and medium channels under uniform flow conditions to fair accuracy having discharge less than 30 cusecs (849.50 L/S). Thrust rod should be as lighter as possible to minimize the effect of buoyancy. Each thrust rod has its limits of applicability depending upon the weight “W_A” required to counterbalance velocity currents. Aluminium rod holds good results as compared to a wooden rod. It was found that the difference behaviour between the determined and measured velocities depends upon the shape and weight of rod. The rod of lighter weight gave better estimates than larger. Whereas, the heavier rod under estimated the flow veocity, because the effect of buoyancy was significant and less weight “W_A” was required to counter balance the water thrust. The percentage eorr in Laboratory conditions was ±3% and Error in distriburies in field was ±5%.The rod of width twice the thickness gave more accurate estimation of velocity.Further studies can be conducted by using the rod of varies diamensions, and physical properties. The thrust rod can be developed for main cananls and rivers.

Acknowledgments

Authors are thankful to the Centre of Excellence in Water Resources Engineering, Engineering University Lahore for providing the required facilities to conduct the study.

5. REFERENCES

1. Acker P., White W R., Perkins J A., Harrison A J M. :Weirs and flumes for flow measurement. John Wiley and sons INC 1978.
2. Awan N M. :Surface Water Hydrology. National Book Foundation Islamabad 1981.
3. BengtsonH. :Use of the Manning Equation for Open Channel Flow in Natural Channels. Journal of Hydraulic Engineering , May, 19 , 2010.
4. Fonstad M A., Reichling., James P., Van D G., Jow W. :Transparent Velocity-Head Rod for Inexpensive and Accurate Measurement of Stream Velocities” Journal of Geoscience education 2005.
5. Tariq. A R., Masood. M. : Deflecting Velocity Rod for Flow measurements in Small channels. Journal of Irrigation and Drainage Engineering, vol.127, No 5, September/October 2001.
6. USBR : Flow Measurement Manual. United State Department of Interior, Bureau of Reclamation 1985.
7. Wilkerson G V., Mcgahan J L. :Depth-Averaged Velocity Distribution in Straight Trapezoidal Channels. Journal of Hydraulic Engineering. Vol.131. Issue 6, 2005.