Velocity Distributions in Grassed Channel

Muhammad Mujahid Muhammad[1, a]
Khamaruzaman Wan Yusof[2, b]

Muhammad Raza Ul Mustafa[3, c]
Aminuddin Ab. Ghani[4, d]

[1, 2, 3]Civil and Environmental Engineering Department, *Universiti Teknologi PETRONAS (UTP)*, Seri Iskandar, Malaysia. [4]River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia (USM), Nibong Tebal, Malaysia. *my*

Abstract*—Studying the velocity distributions in grassed channel such as swale can help in proper design of eco-friendly channel against erosion. To understand the hydrodynamics of vegetated channel, previous studies make use of artificial vegetation to perform laboratory experiments, and this has been challenged by several researches. The present study employed the use of natural submerged vegetation to investigate the velocity distribution within a grassed flume. To achieve this, velocity profiles were measured using Acoustic Doppler Velocimeter (ADV) in order to obtain the stream-wise and vertical velocity profiles along several vertical and cross sections. Evaluation of the experimental results revealed that the velocity profile was not uniformly distributed in channel infested by submerged grass; and the velocity distribution is greatly influenced by the vegetation density. It can be concluded that for a submerged flexible vegetation the velocity profiles for both stream-wise and verticals are being influenced by the grass roughness, geometry and the flow depth. From the results, it was found that the flow depth of 0.15 m has wider velocity range compared to the other depths of 0.20 m and 0.40 m respectively, with the 0.40 m depth having the least velocity range.

***Keywords-** Velocity distributions; Natural vegetation; Submerged vegetation; ADV; Stream-wise velocity; Vertical velocity*

I. INTRODUCTION

A flow field is best described by its velocity distribution, and as such a flow may be classified as either one, two, or three – dimensional depending on the variation of flow velocity in the three coordinate systems. A typical fluid flow can vary in x, y, and z – axes in a rectangular coordinate system or r, Θ, and z in cylindrical coordinates. However, the variation of velocity in certain directions can be small compared to other directions and can be ignored without affecting the overall result [1]. In this regard, the flow field can be simplified and modeled as being one- or two- dimensional, which is easier to analyze.

Although in the hydraulic industry, velocity distributions have been widely investigated, there are still numerous unanswered questions awaiting explanations. For instance, stream-wise velocity profiles, especially in real life vegetated channels with roughness [2]. Similarly, El-Samman [3], studied velocity distribution using artificial vegetation and recommended that furthermore analysis is required to investigate the phenomenon of directing the flow towards the right side in a channel. Velocity distributions with fully developed, steady and uniform flows in open channels with roughed surfaces, have been reported extensively by several researchers [4-8].

There are two familiar velocity distributions for open channel flows, like the power law and the Prandtl–Von Karman universal velocity distribution law [1, 9]. From these two types of velocity profiles can be distinguished in a smooth channel in terms of their shapes as parabolic and logarithmic for laminar and turbulent flow fields, respectively [10, 11]. Figure 1 shows a typical velocity profile in a smooth channel. However, when vegetation is introduced into a flowing channel, the vegetation roughness affects the shape of the velocity profiles in both stream-wise and vertical directions. For example, when the vegetation is submerged, the velocity profile was found to be approximately S-shaped as in Figure 2 [12-15].

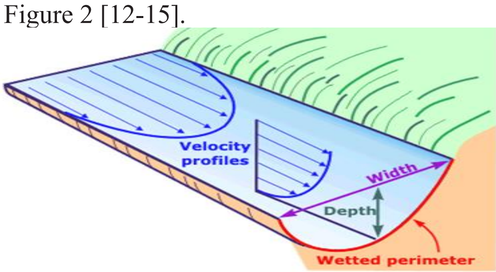

Figure 1. Non-vegetated velocity profile [16].

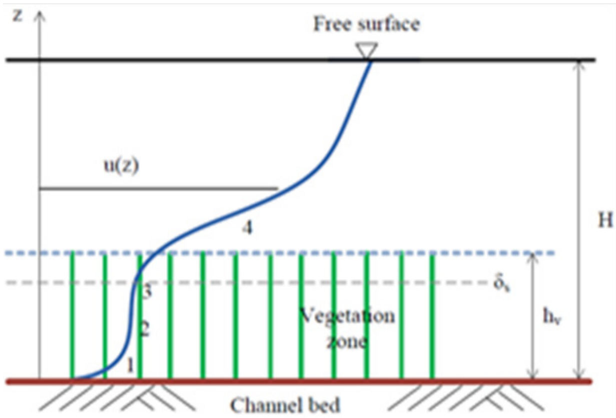

Figure 2. Vertical velocity profile of submerged vegetation.

From the foregoing, it is clear that vegetation need to be controlled in a channel, in order to reduce the flow resistance offered by vegetation, especially if the vegetation is emergent [17]. Thus, aquatic vegetation may have negative consequence on channel's design flow rate, conveyance capacity and permissible velocity, respectively [18, 19].

This research was sponsored by Ministry of Education under HiCOE's niche area Sustainable Urban Stormwater Management, Universiti Sains Malaysia, USM (Grant No. 311.PREDAC.4403901).

4th Annual International Conference on Architecture and Civil Engineering (ACE 2016)

ISSN 2301-394X
doi: 10.5176/2301-394X_ACE16.39

The main purpose of this research is to study the uneven velocity distributions in open channel through the use of real flexible vegetation.

II. MATERIALS AND METHODS

A. *Experimental Procedure*

The experimental work was conducted in a concrete rectangular flume of dimension 12 m length, 1.5 m width and 1 m depth respectively, located at the physical modeling laboratory of River Engineering and Urban Drainage Research Center (REDAC), Universiti Sains Malaysia (USM). The overall length of the flume is 16 m and it consists of three sections which were the inlet sump, the test flume and the outlet sump. Figure 3 shows the Plan view of the test channel.

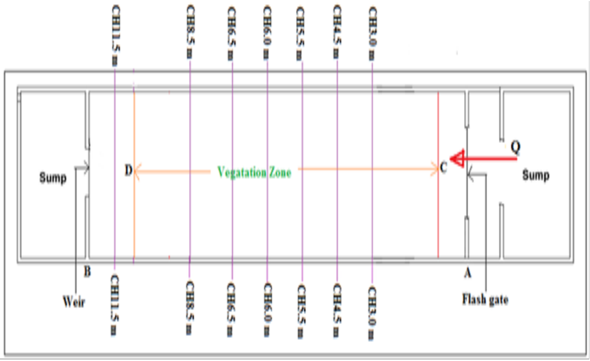

Figure 3. Plan view of test channel

From Figure 3, Axonopus Compressus commonly known as Cow grass was planted over a length of 10 m on a bed slope of 1:1000 in the vegetated zone labelled CD. The average height of the grass was determined to be 50 mm. Figure 4 shows the sample of the Cow grass, while Figure 5 shows the vegetated test channel.

Figure 4. Sample of cow grass

Figure 5. Vegetated test channel

Three different flow depths were used to investigate the interaction of the grass with velocity profile under submerged flow conditions. The flow depths comprised y = 0.15 m, y = 0.20 m and y = 0.40 m, with aspect ratios of B/y = 10, B/y = 7.5 and B/y = 3.75 respectively. Velocity profiles were determined at five different vertical points (that is width of channel 1.5 m divide by 5 equals 0.3 m) measured along 7 – cross sections labelled CH3.0 m as the first cross section, meaning 3.0 m away from the inlet, similarly cross section CH4.5 m, means 4.5 m away from inlet and so forth up to CH11.5 m which is out of the vegetation zone, as shown in Figure 3. Also, at each point 8 different depths were measured in fractions of the flow depths, that is, 0.2y, 0.25y, 0.3y, 0.4y, 0.5y, 0.6y, 0.7y and 0.8y, respectively. Thus, in each cross section 40 – point velocities were observed in both stream-wise and vertical directions. Along these directions the velocities were measured by using Acoustic Doppler Velocimeter (ADV) which determined the velocity in x – and z – directions as stream-wise and vertical, respectively. The ADV measures flow velocity using the Doppler shift principle of moving particles and a 3-15 mm deep sampling volume away from the transducer. For this experiment, the frequency of each data sampling was set to 25Hz in a continuous time interval. In order to obtain a good result from the ADV, the criteria for data sampling and acquisitions were used in terms of sound to noise ratio (SNR) and the correlation coefficients respectively. As a rule of thumb when the value of SNR is not above 15dB and correlation is not more than 70%, the observed velocity should be rejected irrespective of the direction. Also, the measured velocities are influenced by the particles moving along with the water which help in obtaining a better result. As such turbid water was used in this experiment.

III. RESULTS AND DISCUSSION

A. *Stream-wise Velocity Profile*

Tables I, II and III show the measured mean stream-wise velocity profiles (distributions), Vxm, for the respective flow depths of 0.15 m, 0.20 m and 0.40 m along the lateral distance from the left bank and the cross sections. From these Tables, average velocity were determined and Figure 6 was produced to show the variation of the stream-wise velocity. It is obvious that flow depth of 0.15 m has larger average stream-wise velocity range of 0.28 to 0.51 m/s compared to the other depths.

TABLE I. MEAN STREAM-WISE (VXM) MEASURED VELOCITY FOR FLOW DEPTH OF 0.15 m.

	CH3.0 m	CH4.5 m	CH5.5 m	CH6.0 m	CH6.5m	CH8.5m	CH11.5 m	
Distance from Left bank (m)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Average Velocity (m/s)
0.15	0.33	0.36	0.43	0.23	0.53	0.39	0.06	0.33
0.3	0.56	0.73	0.70	0.40	0.52	0.43	0.17	0.50
0.6	0.41	0.35	0.75	0.50	0.59	0.73	0.21	0.51
0.9	0.12	0.56	0.12	0.22	0.83	0.59	0.19	0.38
1.2	0.16	0.10	0.20	0.48	0.35	0.55	0.11	0.28

TABLE II. MEAN STREAM-WISE (VXM) MEASURED VELOCITY FOR FLOW DEPTH OF 0.20 m

	CH3.0 m	CH4.5 m	CH5.5 m	CH6.0 m	CH6.5m	CH8.5m	CH11.5 m	
Distance from Left bank (m)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Average Velocity (m/s)
0.15	0.16	0.26	0.12	0.33	0.25	0.16	0.09	0.20
0.3	0.24	0.26	0.27	0.30	0.16	0.08	0.08	0.20
0.6	0.07	0.15	0.18	0.38	0.22	0.16	0.09	0.18
0.9	0.15	0.15	0.16	0.08	0.29	0.17	0.12	0.16
1.2	0.09	0.12	0.11	0.08	0.43	0.17	0.07	0.15

TABLE III. MEAN STREAM-WISE (VXM) MEASURED VELOCITY FOR FLOW DEPTH OF 0.40 m

	CH3.0 m	CH4.5 m	CH5.5 m	CH6.0 m	CH6.5m	CH8.5m	CH11.5 m	
Distance from Left bank (m)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Vxm (m/s)	Average Velocity (m/s)
0.15	0.07	0.07	0.07	0.05	0.14	0.16	0.04	0.09
0.3	0.06	0.14	0.20	0.24	0.09	0.09	0.04	0.12
0.6	0.29	0.05	0.04	0.07	0.18	0.22	0.03	0.13
0.9	0.08	0.14	0.07	0.09	0.15	0.07	0.04	0.09
1.2	0.09	0.07	0.06	0.05	0.09	0.06	0.03	0.07

Plotting the average stream-wise velocity profiles as in Figure 6, by using a log scale which gives a better trend pattern. From this figure, it can be deducted that when the flow depth was set at 0.15 m the stream-wise velocity profile was higher than the other flow depths. While, the flow depth of 0.4 m shows least velocity profile.

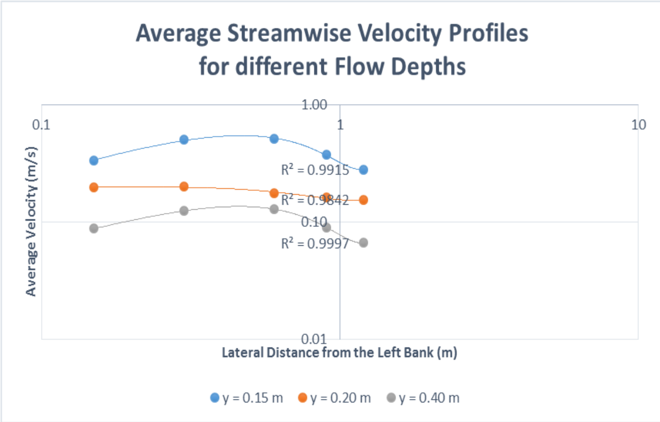

Figure 6. Average stream-wise velocity distribution for the different flow depths.

B. *Vertical Velocity Profiles*

Table IV shows the average centerline vertical velocity profiles of the various flow depths. Using this Table, the vertical velocity profile was plotted in Figure 7, by using a log scale. From this Figure, it shows all the flow depths have the same pattern of velocity profile. However, flow depth of 0.15 m has wider velocity range (0.57 to 1.42 m/s) compared to the other depths. The flow depth of 0.20 m has velocity range of 0.17 to 0.63 m/s, while that of 0.40 m has velocity range of 0.09 to 0.45 m/s.

TABLE IV. AVERAGE VERTICAL VELOCITY DISTRIBUTIONS FOR THE DIFFERENT FLOW DEPTHS

	y = 0.15 m		y = 0.20 m		y = 0.40 m	
Measurement Locations in the Verticals	Water Depth (m)	Average Centerline Vertical Velocity (m/s)	Water Depth (m)	Average Centerline Vertical Velocity (m/s)	Water Depth (m)	Average Centerline Vertical Velocity (m/s)
0.2y	0.03	1.42	0.04	0.37	0.08	0.45
0.25y	0.038	1.11	0.05	0.48	0.10	0.44
0.3y	0.045	0.57	0.06	0.32	0.12	0.32
0.4y	0.06	0.50	0.08	0.63	0.16	0.34
0.5y	0.075	1.15	0.10	0.26	0.20	0.09
0.6y	0.09	0.99	0.12	0.17	0.24	0.10
0.7y	0.105	1.07	0.14	0.16	0.28	0.14
0.8y	0.12	0.67	0.16	0.31	0.32	0.12

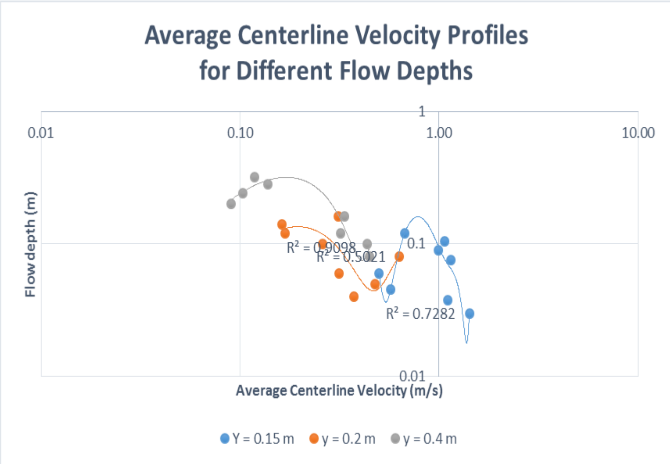

Figure 7: Centerline velocity profiles due to different flow depths.

While, Figure 8 shows the centerline vertical velocity profile along the channel length reach, similarly a log scale was used. Also, the same thing happens with the flow depth of 0.15 m having larger velocity range compared to the rest of the depths.

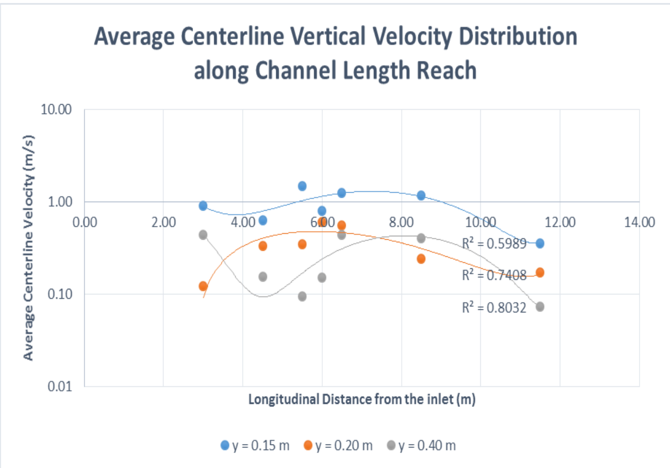

Figure 8: Vertical velocity profile along the channel length reach.

IV. CONCLUSIONS

It can be concluded that for a submerged flexible vegetation in this case Cow grass, the velocity profiles for both stream-wise and verticals are being influenced by the grass roughness, geometry and the flow depth. Thus, in all cases, it is extremely clear that the flow depth of 0.15 m has the highest velocity range compared to the rest of the depths, with the 0.40 m flow depth being the least. And it can be deducted that the presence of submerged grass in a channel had a great consequence on magnitude and flow direction.

Further investigation is required using different vegetation density, vegetation type and geometrical dimensions.

ACKNOWLEDGMENT

We would like to acknowledge the financial assistance from Ministry of Education under HiCOE's niche area Sustainable Urban Stormwater Management, Universiti Sains Malaysia, USM (Grant No. 311.PREDAC.4403901). The first author would also like to acknowledge Universiti Teknologi PETRONAS for the fellowship scheme to undertake the postgraduate study.

REFERENCES

1. Cengel, Y.A. and J.M. Cimbala, *Fluid Mechanics: Fundamentals and Applications*. Third ed, ed. Third. 2014, USA: Mc Graw Hill Education.
2. Maghrebi, M.F. and M. Rahimpour, *Streamwise velocity distribution in irregular shaped channels having composite bed roughness*. Flow Measurement and Instrumentation, 2006. **17**(4): p. 237-245.
3. El-Samman, T.A., Hosny M. M. and Ibrahim H. M. , *Impact of Aquatic Weeds on Water Distribution Efficiency*, in *The 2nd Inter-Regional Conference on Environment - Water Engineering Technologies for Sustainanble Land use and Water Management*. 1999: Switzerland.
4. Balachandar, R., K. Hagel, and D. Blakely, *Velocity distribution in decelerating flow over rough surfaces*. Canadian Journal of Civil Engineering, 2002. **29**(2): p. 211-221.
5. Guo, J. and P.Y. Julien. *Modified log-wake law in smooth rectangular open-channels*. in *Proc. 13th IAHR-APD Congress Singapore*. 2002. World Scientific.
6. Smart, G.M., M.J. Duncan, and J.M. Walsh, *Relatively rough flow resistance equations*. Journal of Hydraulic Engineering, 2002. **128**(6): p. 568-578.
7. Sarma, K.V., P. Lakshminarayana, and N.L. Rao, *Velocity distribution in smooth rectangular open channels*. Journal of Hydraulic Engineering, 1983. **109**(2): p. 270-289.
8. Aberle, J. and G. Smart, *The influence of roughness structure on flow resistance on steep slopes*. Journal of Hydraulic Research, 2003. **41**(3): p. 259-269.
9. Cruise, J.F., M.M. Sherif, and V.P. Singh, *Elementary Hydraulics*. 2007, USA: CENGAGE Learning.
10. Te Chow, V., *Open channel hydraulics*. 1959.
11. Nezu, I., H. Nakagawa, and G.H. Jirka, *Turbulence in open-channel flows*. Journal of Hydraulic Engineering, 1994. **120**(10): p. 1235-1237.
12. Carollo, F., V. Ferro, and D. Termini, *Flow velocity measurements in vegetated channels*. Journal of Hydraulic Engineering, 2002. **128**(7): p. 664-673.
13. Ikeda, S. and M. Kanazawa, *Three-dimensional organized vortices above flexible water plants*. Journal of Hydraulic Engineering, 1996. **122**(11): p. 634-640.
14. Kouwen, N., T. Unny, and H.M. Hill, *Flow retardance in vegetated channels*. Journal of the Irrigation and Drainage Division, 1969. **95**(2): p. 329-344.
15. Temple, D.M., *Velocity distribution coefficients for grass-lined channels*. Journal of Hydraulic Engineering, 1986. **112**(3): p. 193-205.
16. Muhammad, M.M., Khamaruzaman, W. Y., Muhammad Raza, U. M and Aminuddin, Ab. G. *Vegetated Open Channel Flow for Urban Stormwater Management: A Review*. *36th IAHR World Congress*. 2015. The Hague, the Netherlands.
17. Mitchell, D., *Effects of excessive aquatic plant populations*, in *Aquatic vegetation and its use and control*. 1982, UNIPUB. p. 50-6.
18. Guscio, F.J., T.R. Bartley, and A.N. Beck, *Water resources problems generated by obnoxious plants*. Journal of the Waterways and Harbors Division, 1965. **91**(4): p. 47-62.
19. Gwinn, W. and W. Ree, *Maintenance effects on the hydraulic properties of a vegetation-lined channel*. Transactions of the ASAE, 1980. **23**(3): p. 636-642.