Application of ADV Method for Measurement of Flow Velocity Components in the Malina Stream

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Abstract

In this article, the results of velocity profile measurements in a stream by using the ADV method (Acoustic Doppler Velocimetry) are presented. The measurements are carried out in the Malina stream (Záhorie lowland). The velocity profile was measured with using the three-dimensional ultrasound probe of ADV device - FlowTracker (SonTek/YSI). The obstacle, represented with 120-liters barrel, was installed into the stream and by this way the velocity profile was modified. First, the undisturbed velocity profile was measured and subsequently there was measured the modification of this velocity profile caused by the obstacle installation. Velocities were measured in the proposed grid of points; the same grid was used for both cases (without the obstacle, with the obstacle). The grid was created by verticals along the cross-section profile and by several value of depth in each vertical. The vertical lines were proposed in distance 1,25; 1,50; 1,75; 2,00; 2,25; 2,50; 2,75; 3,00; 3,25; 3,50; 3,75 and 4,00 m from the right bank of the stream. Depth of points in each vertical were 0,15; 0,30; 0,45 m from the water level of the stream. The results of the measurement is a database of vx, vy, vz components in the grid points, from which it is possible to determine the velocity profiles of individual components or resultant of these three components of the point velocity. The measurement results confirmed the suitability and applicability of the ADV method represented by FlowTracker 3D to determine the distribution of point velocity components in the cross-section profile. This method, as one of the few ones, allows obtaining the values of the velocity components at any point of flow directly in the field conditions.

Keywords: *ADV method, aquatic vegetation, flow-discharge conditions, stream, velocity profile*

1. Introduction

The flow regime in channels or in surface water at lowland territories during the growing season is often very strongly influenced by the occurrence of aquatic vegetation [1, 2, 3]. From a hydrodynamic point of view, water plants alter the size and distribution of flow velocities at a large rate; they increase the stream bed roughness and decrease the discharge capacity of a stream. As the development of water plants progresses, the coefficient of roughness value is changed. In general, this parameter determines the extent of roughness and impacts the flow capacity of channels or watercourses [4]. The accumulation of vegetation in river channels poses significant challenges to hydraulic dynamics. This study investigates the impact of vegetative debris accumulation on flow characteristics by simulation of the artificial obstaclem which is presented by 120-liters barrel.

A large number of different experimental methods for determining the flow characteristics exist, which can be used in laboratory and field conditions. One of them is based on ultrasonic reflection and uses so-called Doppler effect for velocity value determination. This method allows to measure all three components of velocity in the measuring point - volume also in field conditions [5, 6, 7].

Fig. 1. ADV probe of FlowTracker device (version 3D)

ADV (Acoustic Doppler Velocimeter) digital handheld device for measuring the discharge and velocity profiles – Flow Tracker - SONTEK/YSI measures the flow velocity on the principle of ADV [8]. The principle of this method is as follows: the ultrasonic pulse with a given frequency is emitted to specific distance [9]. By crossing the flowing water the pulse frequency is changed and subsequently detected by receivers as a result of reflection from moving particles. Geometry of the receivers may be different. It depends on whether the 2D or 3D probe is used. In our case, the 3D probe has been used with two receivers forming one plain and with third receiver located above this plane (Figure 1). Device can be used in water depths as shallow as 10 cm and in velocities in the range of 0.001 to 4,5 m.s-1 with an accuracy of ± 1 % of measured velocity. The length of measurement can be set in the range from 10 to 1000 seconds. FlowTracker does not measure the velocity of the water directly. The device measures the velocity of solid particles, small organisms, and bubbles suspended in the water, assuming that these particles travel with the same velocity as flowing water

2. Measurement Methodology

Measurements were performed in Malina stream (Figure 2) with steady uniform flow conditions. Malina river is a sewer river in Záhorie lowland, flows through the territory of Malacky district. It is a left tributary of Morava river, has a length of 47.75 *km*. Catchment area is 516.6 km^2 and her discharge is 0.828 $m^3.s^{-1}$ in Jakubov village 2.234 $m^3.s^{-1}$ in the estuary. Value of discharge was 0.642 $m^3.s^{-1}$ during the measurement.

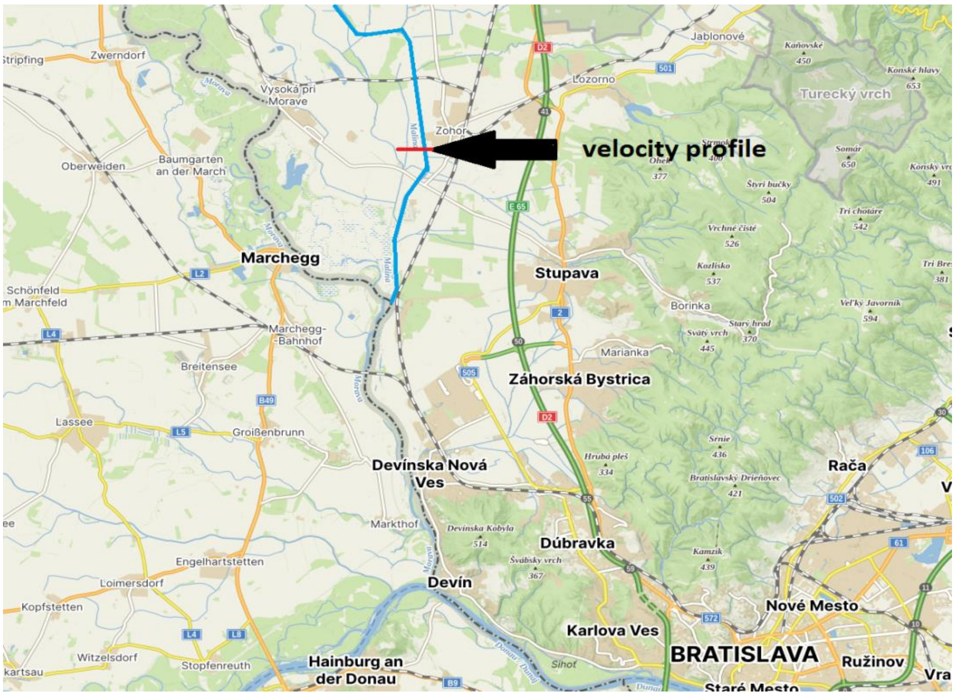

Fig. 2. Measurement site at the Malina stream

As a measuring device there was used the ADV FlowTracker 3D probe. Many "aquatic" scientists employ ADV to characterise flow conditions [10, 11]. The technique relies on the Doppler shift principle to measure the velocity of suspended scattering particles that are assumed to move passively with the flow. The ADV conducts 3 component current measurements in a sampling volume below the transmit-transducer. Sound bursts of known duration and frequency are emitted by the central transmitter and subsequently reflected back by suspended particles moving through the sampling volume. The reflected signals that are shifted in frequency (Doppler shift) are collected by the three receivers that surround the transmitter.

The magnitude of the frequency shift is proportional to the velocity of the reflecting particles. During the experiments it was applied so-called "General Mode" of ADV FlowTracker 3D probe. This mode allows to measure velocity components in any measured point grid. In the first step, the measurements were carried out in profile, in which the flow is not disturbed – it means without any barrier. In the second phase, we placed a 120-liters barrel to the Malina river, which changed flow conditions and velocity component fields (Figure 3). The diameter of the barrel was 0.5 *m* at its widest point and the height was 0.85 *m*.

The barrel was filled to the brim with water and was placed 0.5 m (distance *L1*) upstream from the cross-section profile. The measurement grid was created by different verticals along the Malina stream width. We selected the verticals in distance 1.25; 1.50; 1.75; 2.0; 2.25; 2.50; 2.75; 3.00; 3.25; 3.50; 3.75; 4.00 *m* from right bank of the Malina stream (distance *L2*). Point velocity components v_x, v_y, v_z were measured at 3 different heights in each vertical. Heights of measured points in the verticals were 0.15; 0.30 and 0.45 *m* (distance *H*) from the water level. In the verticals $L2$ = 3.75 and 4.00 *m* from the right bank, only velocities at heights of 0.15 and 0.30 *m* (*H3* and *H2*) were considered. Reason is the influence of aquatic vegetation on the Malina stream bottom (the value of v_x reached only 0.005 $m.s^{-1}$). The measured velocities were not included in the summary results. The grid of measuring points in cross-section profile was identical for all measurements. The marking of the measured points in the graphs is as follows: for a profile without an obstacle it is from *H1* to *H3* and for a profile behind an obstacle it is from *H1B* to *H3B*. Figure 3 shows distribution of the velocity components measured points in the profile behind the obstacle. We set the measurement time (t) at individual points on 180 *seconds* for the profile without an obstacle and 300 seconds behind the obstacle.

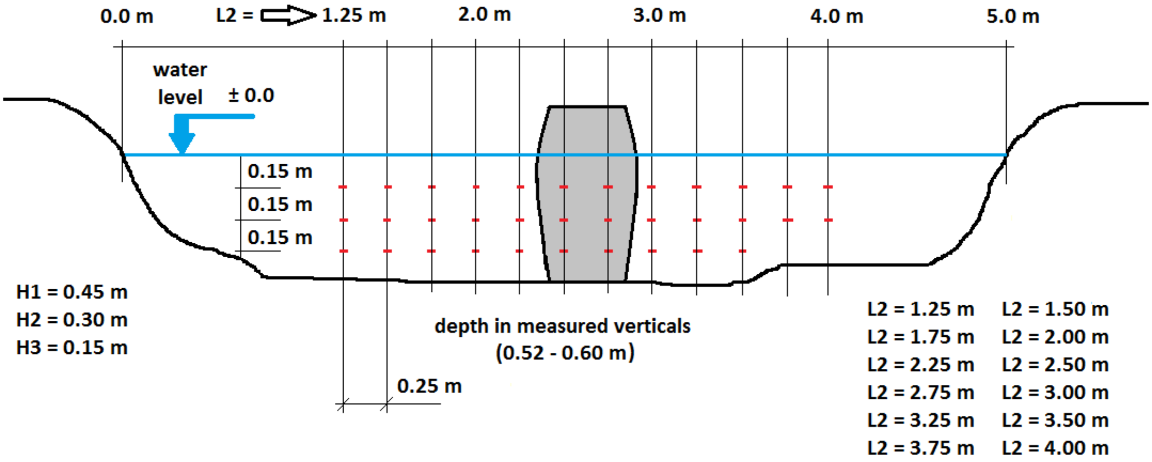

Fig. 3. Arrangement the vertically axis and depth measurement point of the velocity components

3. Results

The result of the measurement is the database of v_x, v_y, v_z components in the selected points, from which it is possible to determine the velocity profile of individual components or resultant of these three components of velocity (for three different depths below the water level). These courses of velocities components v_x, v_y, v_z at individual points in the verticals of measured profiles (profile without barrier, profile behind the barrier) are plotted on the Figure 4, Figure 5 and Figure 6. Dashed lines are used for values in the profile without an obstacle, no-dashed lines for values in the profile behind the obstacle.

The shape of v_x course in case of profile without any barrier is relatively regular in each vertical (Figure 4). The highest values are recorded in the streamline for all three investigated depths, and towards to the banks values decrease. For the profile behind the obstacle, values are almost identical with the profile without the obstacle (except for verticals from *L2* = 2.25 *m* to *L2* = 2.75 *m*); axis of the located obstacle is at a distance of 2.625 *m* from the right bank of the stream. The greatest reduction in the v_x velocity values is recorded at the depth of H3S (0.15 meters below the water level) - only 17.5% from velocity value in the profile without obstacle (from 0.480 $m.s^{-1}$ to 0.084 $m.s^{-1}$). In the other measured depths, this difference is smaller (54.43 % from velocity value in the profile without obstacle - for *H2B* depth; and 25.92 % from velocity value in the profile without obstacle - for *H1B* depth. **Table 1** shows the average, maximum and minimum values of the velocity components v_x, v_y, v_z in the three measured depths (0.45; 0.30 and 0.15 *m*). Table also shows the percentage difference between the average velocity components values v_x, v_y, v_z measured in the profiles without/with an obstacle. For profile behind the obstacle the average velocity values v_x are in the range of 71.84 to 85.75% from velocity value for profile without the obstacle.

In the case of the component v_y (Figure 5), the situation is follows: for profile without an obstacle, progress of the component v_x across the stream width is relatively stable and oscillates around the zero value. For profile behind the obstacle results show fluctuation of this velocity component, as a consequence of the inserted obstacle. As a result, deformation of the liquid flow occurs. Maximum change in this velocity component value is in the vertical line *L2* = 2.5 *m* from the right bank at the *H3B* depth. The component value is at this point -0.25 $m.s^{-1}$ (**Table 1**). Left side of the obstacle was not observed swing of this velocity component as on the right side. The swing on the left side is smaller. This may be caused by the imprecise centering obstacle in the streamline, respectively greater occurrence of aquatic vegetation. Figure 5 shows, that largest deformations were recorded at the depth of *H3B*, because as a result of the placed obstacle, there is also a deformation of the water level behind it.

The component v_z oscillates around the zero value due to inserted obstacle and can have a positive or negative sign. Figure 6 shows values of progress component v_z. For profile without an obstacle, progress the component v_z along the stream width is relatively stable and oscillates around the zero value. For profile behind the obstacle, situation is almost identical except for velocities values in the vertical *L2* = 2.5 m in the depths *H1B* (velocity value v_z = 0.106 $m.s^{-1}$) and *H3B* (velocity value v_z = -0.103 $m.s^{-1}$). The flowing liquid was directed to the water level in *H3B* and to the bottom in *H1B*. Other velocity values v_z are in the ± 0,002 $m.s^{-1}$ range.

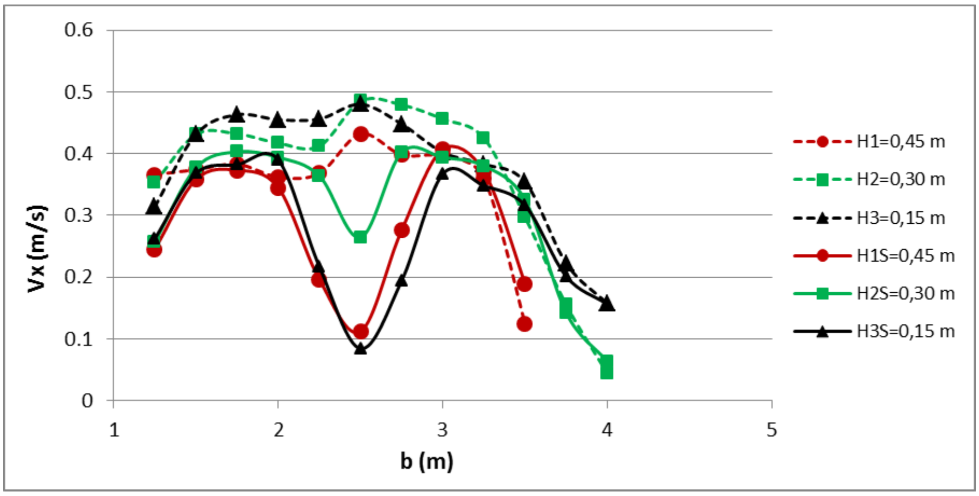

Fig. 4. Measurement of velocity component v_x in the velocity profile without and behind the barrier

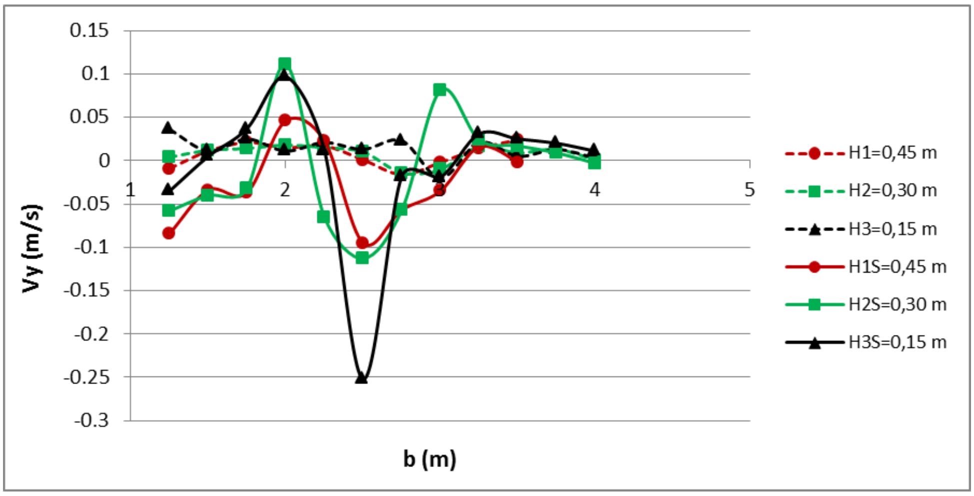

Fig. 5. Measurement of velocity component v_y in the velocity profile without and behind the barrier

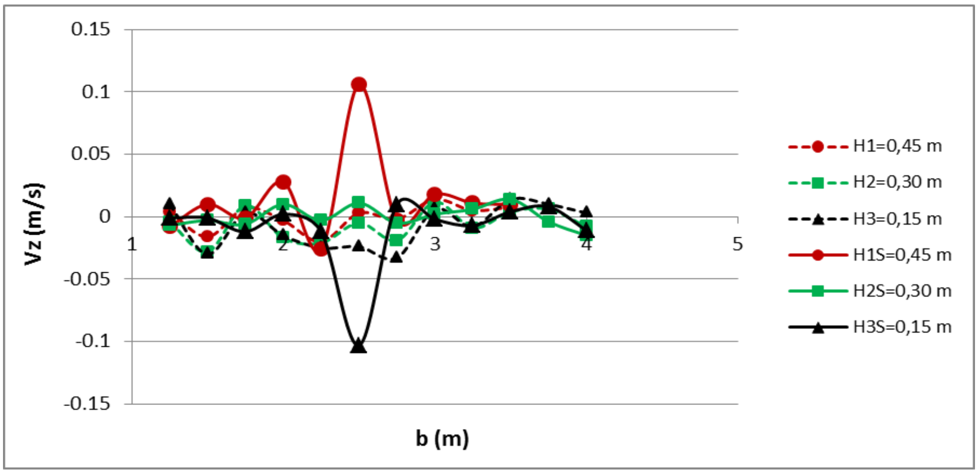

Fig. 6. Measurement of velocity component v_z in the velocity profile without and behind the barrier

Tab. 1. Velocity components (v_x, v_y, v_z) values in three measured depth (minimum, maximum and average values).

		H1 (0.45 m)			**H2 (0.30 m)**			**H3 (0.15 m)**	
	min	max	aver.	min	max	aver.	min	max	aver.
v_x ($m.s^{-1}$)	0.124	0.432	0.356	0.044	0.485	0.365	0.157	0.480	0.380
v_y ($m.s^{-1}$)	-0.016	0.076	0.024	-0.014	0.018	0.007	-0.020	0.036	0.013
v_z ($m.s^{-1}$)	-0.020	0.014	0.001	-0.028	0.012	-0.007	-0.033	0.014	-0.007
		H1B (0.45 m)			**H2B (0.30 m)**			**H3B (0.15 m)**	
v_x ($m.s^{-1}$)	0.112	0.407	0.287	0.063	0.403	0.313	0.084	0.390	0.273
v_y ($m.s^{-1}$)	-0.095	0.046	-0.025	-0.113	0.111	-0.010	-0.252	0.097	-0.007
v_z ($m.s^{-1}$)	-0.026	0.106	0.014	-0.015	0.014	0.001	-0.103	0.010	-0.010

4. Conclusion

The measurement results confirmed feasibility and applicability of the ADV (Acoustic Doppler Velocimeter) method, represented by FlowTracker instrument, for determination of the current velocity characteristics in the open flow conditions. This method allows obtaining even the values of the velocity components at any point in a stream. Advantage is the possibility of choosing location and density of the measured points in the stream, respectively in the measured area.

A slow flowing stream was chosen for the measurement in order to minimize deformation of the component values v_x, v_y, v_z for profile without inserted obstacle. The components values v_y a v_z confirmed by their oscillation, correctness choice of sream type for this case. During measurements behind the obstacle, velocity components values v_x, v_y, v_z were deformed in a way, that corresponded to assumed deformation of the velocity field.

Pilot measurement experience has also highlighted the suitability of extending the measurement time interval at one point. The time interval of measurement at each point was selected relatively short for the large volume of measurements. In the future, it would be appropriate to carry out such measurements with the choice of a longer time interval of measurement at one point (about 500/600 seconds), especially in the case of an obstacle in the flow and the examination of the velocity field changes. It is essential to analyze the impact of the time interval on the accuracy of the measured value. Another stream of water flow with higher flow rates is also considered.

Acknowledgments

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References

1. C. Farkas, G. Gelybó, Z. Bakacsi, Á. Horel,L. Dobor, I. Kása and E. Tóth, “Impact of expected climate change on soil water regime under different vegetation condition”, Biologia 69, 1510 – 1519, 2014.
2. J. Jarvelä, “Flow resistance of flexible and stiff vegetation: a flume study with natural plants”, J. Hydrol. 269, 44 – 54, 2002
3. C. A. M. E. Wilson, “Flow resistance models for flexible submerged vegetation”, J. Hydrol. 343, 213 – 222.
4. Y. Velísková, R. Dulovičová and R. Schügerl, “Impact of vegetation on flow in a lowland stream during the growing season”, Biologia 72, 840 – 846, 2017.
5. Z. Chára, V. Matoušek, “Comparative study of ADV and LDA measuring techniques“, 6th International Symposium on Ultrasonic Doppler Methods for Fluid Mechanics and Fluid Engineering, Prague, 2010, pp. 33 – 36.
6. J. H. Pu, “Universal Velocity Distribution for Smooth and Rough Open Channel Flows”, Journal of Applied Fluid Mechanics 6, 413 – 423, 2012.
7. E. S. Yochum, B. P. Bledsoe, C. L. G. David, and E. Wohl, “Velocity prediction in high – gradient channels” Journal of Hydrology 424 – 425, 84 – 98, 2015.
8. SonTek, “FlowTracker Handheld ADV Technical Manual,” Firmware Version 3.7, Software Version 2.30 – SonTek/YSI, San Diego, pp. 126, 2009.
9. Y. Velísková, R. Dulovičová, M. Bara, Z. Chára, „Testing of ADV probe at measuring change of velocity profile behind the obsacle“, Acta Hydrologica Slovaca 13 423 – 429, 2012.
10. F. G. Carollo, V. Ferro, D. Temini, „Flow velocity measurements in vegetated channels“, J. Hydraul. Eng ASCE 128, 664 – 673, 2002.
11. S. C. Kim, C. T. Friedrichs, J. P. Y. Maa, L. D. Wright, „Estimating bottom stress in tidal boundary layer from acoustic Doppler velocimeter data“, J. Hydraul. Eng. ASCE 126, 399- 406, 2000.