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Flow Measurement in an Open Channel by UVP

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ABSTRACT

Measuring velocity distribution is required in order to understand the structure of environmental flow well, because environmental flow is complex in structure in comparison with industrial flows. Velocity distribution is obtained by measuring velocity at some points in space or the depth of the river, using several kinds of assumptions. Because many of the existing velocity meters can measure velocity only at a single point in space, velocity distribution measured by the existing velocity meters includes the time lag of measurement. Therefore velocity distribution estimated by these methods must include some error. UVP has been used for a measurement of discharge in a pipe etc because it can measure the instantaneous velocity distribution on a measurement line. And high accuracy of measurement of pipe flow has been certified. From this feature, it is thought that UVP is useful to measure environmental flow. So in this study, discharge in an open channel was estimated by UVP. It was quantitatively evaluated by comparison with discharge in a pipe. Its adaptability to environmental flow was evaluated. Discharge in an open channel estimated by UVP agreed well with that of a pipe, with a difference between both less than 10 %

Keywords: Flow in an open channel, Velocity distribution, Discharge and UVP

INTRODUCTION

In river management, it is important to forecast areas that have possibility of a flood by measuring temporal change of flow rate of the river. Controlling a spread of pollutant is a key issue in environment management. For these purposes, measurement of flow field is essential. From such a viewpoint, requirement of a precise measurement (time dependent if possible) of environmental flow like river or lake is rapidly increasing.

Concerning flow velocity measurement in the river, flow varies according to conditions like the bottom surface or shape of the cross section. So environmental flow field is strongly distributed in three-dimensional space in comparison to industrial flows which can be mostly modeled as one or two-dimensional in space. In order to measure velocity distribution more accurately, measuring the velocity at many points is required. But, because many of the existing flow meters like electromagnetic meter are pointwise measurement, only at a single point in space, a long time is needed to obtain velocity distribution and the measured result includes errors due to a time lag of long measurement. In order to avoid such temporal inaccuracy, various hydrological methods have been used based on strong simplifications and assumptions like Manning's formula[1] Based on such assumptions, discharge is estimated using the measured value of the velocity at only some point in space or the depth of the river. Since assumptions are very crude and actual velocity distributions are different from theoretic value, this becomes one of the causes that enlarge measurement uncertainty of discharge. Therefore, development of new techniques of measuring instantaneous velocity distribution like Ultrasonic Velocity Profile measurement method (UVP) or Acoustic Doppler Current Profiling instrument (ADCP) has been strongly required.

The aim of the present investigation is to apply the UVP to several environmental flows. Actually, though river discharge has been measured using ADCP by Morlock (1996)[3] or Kizawa (2001)[4] etc., the measurement uncertainty has not been examined properly, because actual river discharge is unknown. As a first step, the discharge in an open channel was estimated from velocity distributions measured by UVP, and it was quantitatively evaluated by comparison with discharge in the pipe (reference value) also measured by UVP. Though UVP can measure velocity vector at an intersection of two or three measurement lines, vector measurement takes more time than the one-dimensional (1D) velocity distribution measurement. As a method that requires smaller time lag of measurement, measurement of 1D velocity distribution was performed in this experiment. Firstly, a flow that could be assumed well to be 1D flow was measured. Next, a flow that is 2D was measured. The errors from reference values in each test were estimated. Based on the results of this test, adaptability of UVP to environmental flow was evaluated.

EXPERIMENTAL METHOD

･Experimental equipment

Figure 1 illustrates the test channel of this experiment. In order to make a flow steady, water was filled in an overflow tank by a pump and flowed to the open channel through the vinyl chloride pipe (1) from overflow tank. Discharge was controlled by a manually operated valve (2). The inside diameter of the pipe is 194 mm. Test section 1 is located at the end of this pipe and reference discharge of the channel was measured there. A transducer was set at the angle θ of 8 degrees leaning from a vertical line. The main channel has a reservoir tank at the upstream (3) and a dam at the down stream (4). Height of the dam was 268 mm. Two partition boards are set up on it (5). Their width is 70 mm. The distance from the end of the tank to the tip of the dam is 4000 mm, and the width is 620 mm. The section from the tank to the dam was defined as an open channel. The bottom surface and the interior wall of the open channel are made of wood. The x-axis, y-axis, z-axis were defined to the direction of the main stream, the direction of the vertical line of the wall, the direction of the vertical line of the bottom. The origin was set at the end of the tank. Test section 2 was located in an open channel. As shown in figure 2, a single transducer was set at the position of 2410 mm from the dam (9 times of a height of the dam) with the angle θ equal to 16 degrees leaning to an upstream side from a vertical line. Its head was immersed in water. It was moved by a sliding motor in order to obtain velocity profiles at any *y*-coordinates.

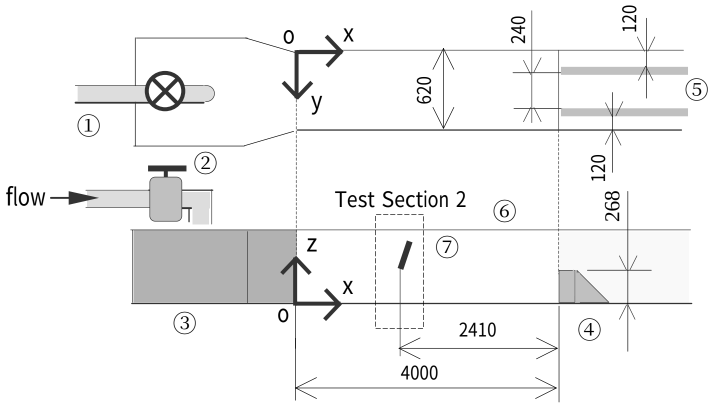


Figure 1: The test channel.
1 Pipe (Test section 1) 2 Valve 3 Reservoir Tank 4 Dam
5 Partition boards 6 Open channei (Test section 2)
7 Transducer

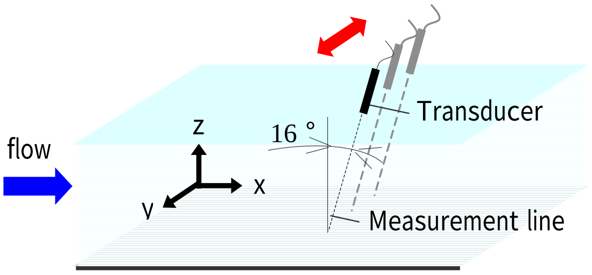
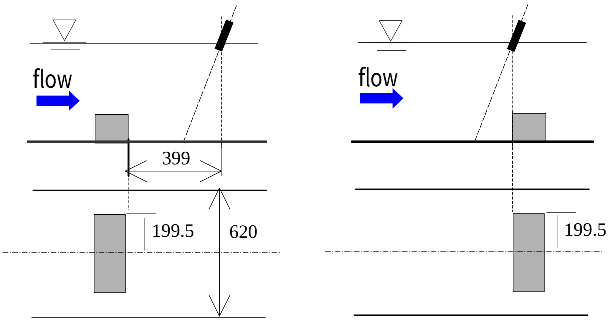


Figure 2: Test section 2.
(Transducer was moved flom y=10 to 310)



test 2-1 test 2-2

Figure 3: Setting of the block in test 2-1 and test 2-2.

At the test section 2, firstly, velocity distribution was measured without any obstruction in the channel, being assumed as 1D flow (called test 1). Secondly, a block was placed on the bottom in order to measure flow that was disturbed and not 1D flow (called test 2). The size of the block; length was 399 mm, width was 99 mm, height was 99 mm. The setting of the block is illustrated in figure 3. It was set perpendicular to the wall at the center of the channel. Measurement was made for two places of the block. In the test 2-1, the block was located at 399 mm (equal to length of the block) upstream from the head of the transducer. In the test 2-2, the block was located down stream of the head of the transducer.

・Experimental method

At the test section 1, discharge of pipe flow was measured by udFlow (Tokyo Electric Power Company). It was a flow meter applying the principle of UVP, and its high accuracy was certified in the several certification tests[5]. So this discharge was adopted as a reference discharge of this channel. Basic frequency of transducer for emitting ultrasonic pulse was 2 MHz.

At the test section 2, velocity distribution was measured by using an Ultrasonic Doppler Velocity Profiler (Met-flow, UVP DUO). Symmetrical flow to a center was assumed. Measurement was made on 30 lines, where *y*-coordinate was 5 mm interval from 10 to 60, 10 mm interval from 60 to 220 and 20 mm interval from 220 to 310. In the test 1 and 2, basic frequency of transducer was 4 MHz. Velocity resolution of UVP DUO was set as about 5.0 mm/s and its spatial resolution was set as about 3.8 mm. Mean velocity distributions on each measurement line were obtained as an average of 512 profiles (about 50 sec).

The test 1 was performed in four cases by changing discharge, and called case 1, 2 ,3 and 4. The smallest discharge was 22 l/s (case 1), and the largest discharge was 46 l/s (case 4). In the test 2, discharge was same as case 3 (about 36 l/s).

Both the test section 1 and 2, tiny bubbles in water were used as tracer to reflect an ultrasonic pulse. Measurements were performed simultaneously at the test section1 and 2, and the discharge at test section 2 was compared with the reference value at the test section 1.

・Data Treatment

UVP can obtain the velocity component along a measurement line, but the direction of actual velocity vector is unknown by a single transducer. In this study, flow in an open channel was assumed as 1D flow. The *y*- and *z*-components of velocity (v_y and v_z) were assumed to be nearly 0. The component of a measurement line of velocity was converted to the *x*-component of velocity. The *x*-component of velocity was calculated as,

$$v_x = v_0 / \sin\theta \tag{a}$$

where v_x is the *x*-component of velocity, v_0 is the component of a measurement line of velocity, θ is an angle of the transducer.

Discharge of the open channel was then calculated by integrating velocity distribution about the direction of y and z.

$$Q = \iint v_x dzdy \quad .$$

The error of discharge in the open channel was defined as a difference from the reference discharge in the pipe, and was calculated as,

$$e = \frac{\left| Q_{Pipe} - Q_{Channel} \right|}{Q_{Pipe}} \times 100$$

where Q_{Pipe} is a discharge in the pipe, $Q_{Channel}$ is a discharge in the open channel.

RESULTS AND DISCUSSION

・Results of test 1

Figure 4 shows a 1D velocity profile at the center of the channel (y = 310) in case 2. The horizontal axis is v_x, and the vertical axis is a distance from the head of the transducer. Each point shows the average v_x, and each error bar shows a standard deviation of v_x at each position. Distance equal to 0 is the head of the transducer and the point that v_x nearly equal to 0 (about 399 mm) is decided as the bottom surface. The more close to the bottom, standard deviation is larger. This is because departure from 1D assumption of flow might be large by the influence of roughness of the bottom surface near the bottom. If UVP is used, not only average discharge but also time fluctuation of discharge can be estimated by standard deviation of velocity.

Next, the 2D velocity distribution in the cross section was measured. Figure 5 shows such velocity distributions in case 2 and case 4. The figure is for the region from the side wall to the center of the channel (half of the cross section). The horizontal axis is *y*-coordinates, and the vertical axis is *z*-coordinates. V_x is expressed by gray scale. Because of friction on the solid surfaces, flow velocity is small near the bottom surface and the side wall. Velocity near the free surface is also small. The reason might be that the head of the transducer changed the flow direction. The velocity component along a measurement line was nearly 0 because direction of a flow became nearly parallel to the surface of the transducer near its head. Because of the time lag of measurement, current measurement methods using the existing flow meter could not obtain such 2D distributions. But if UVP is used, the 2D distribution can be obtained with smaller time lag, and 2D flow structure which has not been understood correctly until now can be clarified.

Based on the 2D velocity distributions, flow discharge was estimated. Figure 6 shows the result. Horizontal axis is reference discharge measured by udFlow. Horizontal bars mean its standard deviation. The vertical axis is discharge in the open channel. Vertical bars mean standard deviation estimated by the standard deviation of velocity. As a tendency, discharge in the open channel agrees well with the reference discharge line. Since the range of standard deviation bars overlap with the reference discharge line, it is thought that discharge estimated by UVP is highly reliable. The error was estimated to be about 7% in case 1&2 and about 2.5% in case 3&4. The main cause of this error might be an inaccuracy of the angle θ of the transducer. In this experiment, v_x was calculated by formula (a). So when θ is small, the influence of the inaccuracy of an angle becomes larger. The second cause of the error was the unmeasured region. Because the head of the transducer was immersed in water, flow velocity was not measured in the region between the head of the transducer and the water surface. The length under water of transducer was about 5 mm. Since the water depth was about 400 mm, the unmeasured region was less than 2%. Therefore if the measurement field has deep water depth, the influence of the unmeasured region may be negligible. Consequently in order to make an error of discharge smaller, countermeasures must be taken. For example, making the angle of fixing equipment correctly, or increasing the angle θ.

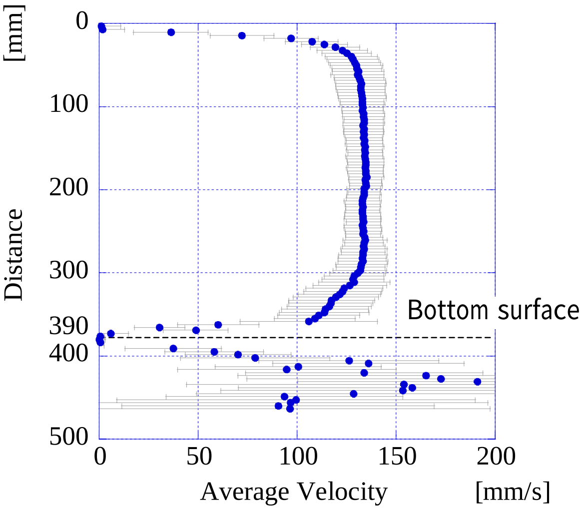


Figure 4: 1D mean velocity profile at y=310 mm (center of the channel) in case 2.

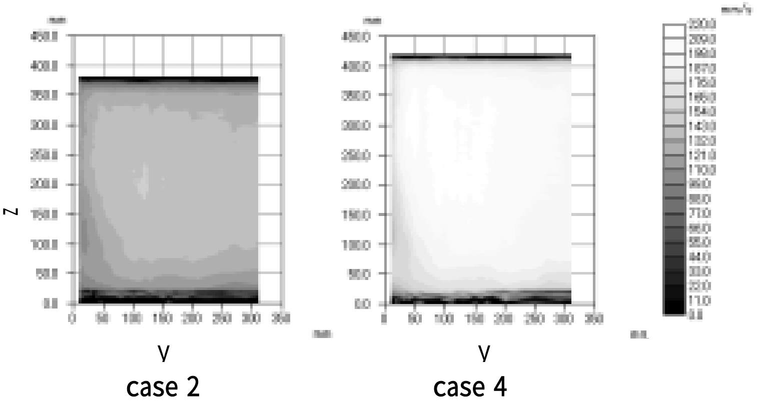


Figure 5: Velocity distribution in case 2 and case 4.

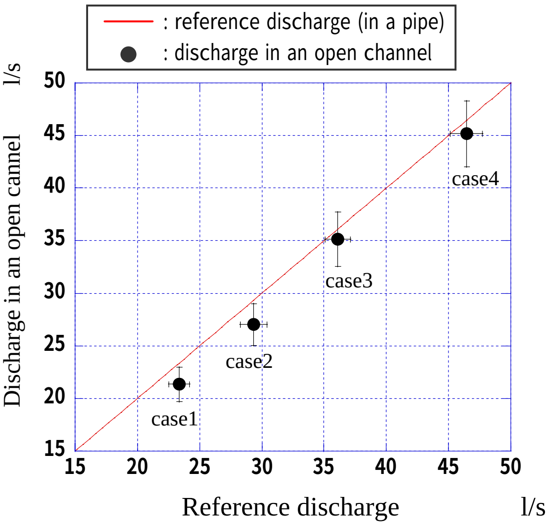


Figure 6: Discharge of pipe flow and open channel

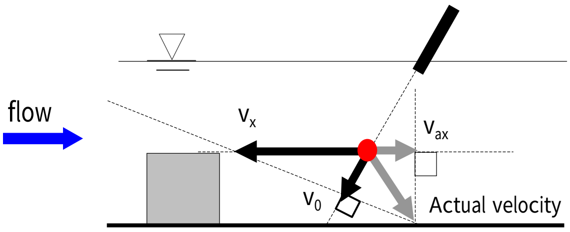
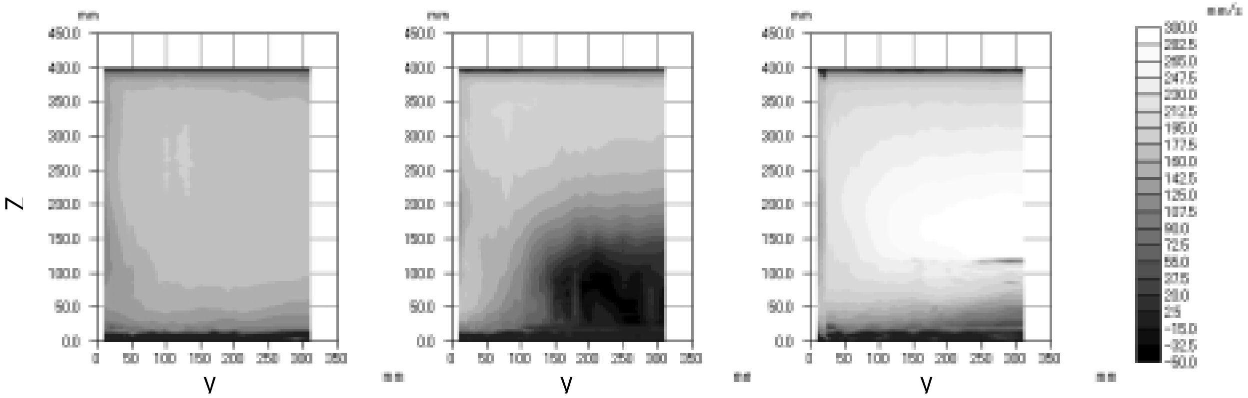


Figure 7: model of test2-1

(v_0: the component along a measurement line of velocity, v_x: the x component of velocity, v_{ax}: the x component of actual velocity)



case 3 **test 2-1** **test 2-2**

Figure 8: Velocity distributions in case 3,test 2-1,and test 2-2

・**Results of Test 2**

In this test, the block was placed on the bottom of the open channel and 3D flow was prepared. The aim of this test was to measure a flow that is not 1D flow by single transducer, and to evaluate the accuracy.

Figure 8 shows the velocity distributions. Horizontal axis is *y*-coordinates, and the vertical axis is *z*-coordinates. Case 3 is the case measured without obstruction in the channel. In test 2-1, v_x is negative in the region behind the block. The reason might be the change of the direction of actual velocity vector by the block. The model of test 2-1 is shown in figure 7. In this region, it flows downward and the flow is not 1D flow. As shown in figure 7, v_x is estimated as negative if the component along a measurement line of velocity is changed into v_x by formula (a), though *x*-component of an actual velocity vector is positive.

In test 2-2, v_x is larger in the whole region compared with case3. In this region, it flows upward. As shown in figure 9, v_x is estimated larger than the *x*-component of actual velocity vector if v_x is calculated by formula (a).

Thus when 2D or 3D flow is measured by a single transducer, v_x measured by UVP is different from the *x*-component of actual velocity.

Based on the velocity distribution so obtained, the discharge in the channel was estimated. The result of discharge is shown in figure 10. Vertical axis is a discharge in the pipe (reference value) and in the open channel. Discharge in the test 2-1 is larger than the reference value. Discharge in the test 2-2 is smaller than the reference value. Because v_x was different from the actual value as discusses above, a difference of discharge is fairly large. The error is about 2.7 % in case 3, while they are about 23 % and 29 % in test 2-1 and 2-2. This result indicates that, in order to perform highly precise measurement using a single transducer, it is very important to choose a measurement point which could be assumed well as 1D flow. Furthermore, in order to measure 2D or 3D flow correctly, velocity vector must be measured using two or three transducers.

CONCLUDING REMARKS

The conclusions of this study are the 1) the error of discharge based on velocity distribution by UVP could be less than 10 % if appropriate measurement point is chosen, and 2) in order to perform highly precise measurement using a single transducer, a measurement point which could be assumed well as 1D flow must be chosen.

Velocity distribution in the cross section measured by UVP was very useful to understand the structure of environmental flow.

The results concluded, when single transducer is used, UVP might be very applicable for environmental flow that could be assumed as 1D flow.

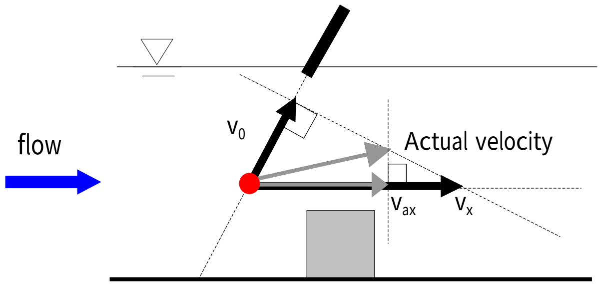


Figure 9: model of test 2-2

(v_0: the component along a measurement line of velocity, v_x: the x component of velocity, v_{ax}: the x the actual velocity vector)

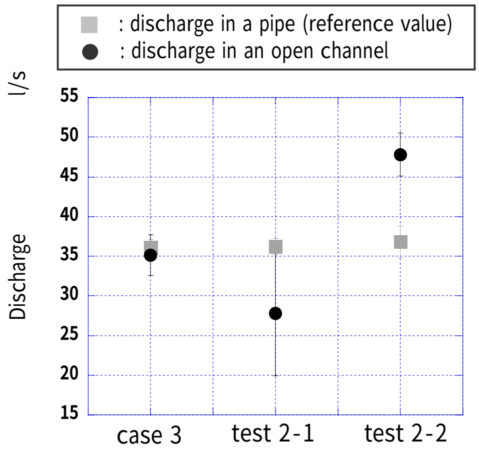


Figure 10: Discharge of pipe flow and open channel in case 3, test 2-1, and test 2-2.

REFERENCES

1. Japan Society of Civil Engineers, 1957, *The collection of formulas of hydraulics*, pp 8-14
2. Y Takeda, 1995, Instantaneous Velocity Profile Measurement by Ultrasonic Doppler Method. *JSME International Journal, Series B, Vol.38, NO.1*, pp.8-15
3. Morlock, S.E., 1996, Evaluation of acoustic Doppler current profiler measurements of river discharge, *U.S. Geological Survey Water-Resources Investigations Report 95-4218*, 37pp
4. K.Kizawa and Y Ide, 2001, The Suggestion of New Observation Techniques about River Discharge, *Symposium about the technique of river maintenance and management*, pp 251-256
5. M Mori et al, 2002, Development of a novel flow metering system using ultrasonic velocity profile measurement, *Experiments in Fluid* 32, pp 153-160.