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Vector Measurement of Environmental Flow Field by UVP

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ABSTRACT

In recent years, environmental flow fields have various problems such as pollution, flood etc. Therefore, request of measurement of environmental flow fields has been increasing. In general currently, these flow fields are measured by electromagnetic current meters or propeller meters. But those techniques are time consuming and of high cost to obtain flow field because they are point measurement. Furthermore their accuracy is too low. The aim of this study is to measure velocity vector in open channel flow field above the dam model. Flow rate was estimated from the measured vector field. The applicability of vector measurement for environmental flow field was confirmed qualitatively and quantitatively.

Keywords: environmental flow field, UVP, velocity vector, open channel

INTRODUCTION

The measurement of environmental flow fields is very important for river conservation works. If flow field information is not acceptable in their works, various problems, for instance, pollution and flood etc. may occur. Therefore, an increasing number of sectors and authorities are interested in the measurement of environmental flow fields. A lot of measurement techniques were developed for environmental flow. For example, Utami, T and Ueno, T. measured two dimensional stream line of river surface by visualization [1].

Flow rate of rivers is one of the most important quantities by which water management is well performed. It has two essential characteristic factors; accuracy and temporal change. Both factors are required to be satisfactory simultaneously.

Essentially, environmental flow is highly three dimensional. However, at present, flow rate of river is measured, in most cases, using electromagnetic current meters or propeller meters which are pointwise and no flow structure is taken into account. This is the reason why high accuracy cannot be attained.

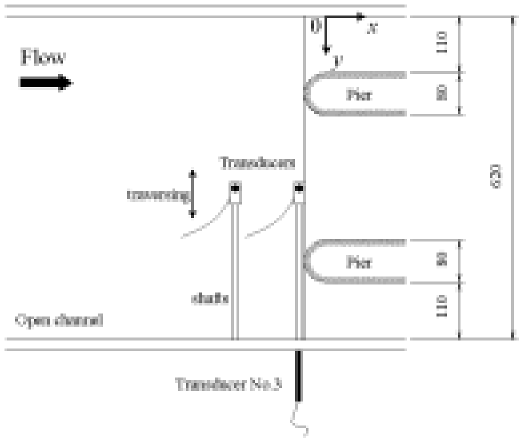
The Ultrasonic Velocity Profiler (UVP) [2] has been used in various environmental flow configurations. V. Bares and V. Boza carried out flow mapping at river model [3]. D. S. Hersberger measured three dimensional flow field in a 90 degrees bend of open channel [4].

In this study, we attempted to make a vector measurement as a basis for flow measurement using an open channel loop with dam model, which is a model of river flow. Flow rate was estimated using the obtained vector field. As a result, applicability of UVP for environmental flow measurement was evaluated in quality and quantity.

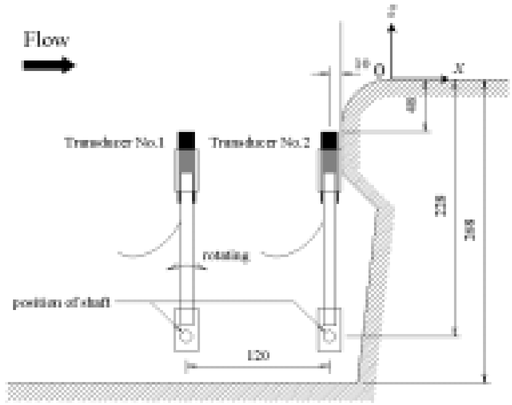
EXPERIMENTAL SETUP AND METHOD

Experiments were performed with an open channel loop in the R&D center of Tohoku Electric Power Company, as illustrated in Fig.1. It consists of an overflow tank, a pipe, a valve, a reservoir tank, an open channel and a dam model. Water is circulated via the overflow tank by the pump. It flows through the pipe, collected in the reservoir tank, the open channel again, and then it overflows the dam model. The pipe diameter is 196 [mm]. Open channel is 4000 [mm] long, 620 [mm] wide and 1120 [mm] high between the reservoir tank and the dam model. Flow rate is controlled by the valve as about 8.5,14.0 and 21.1 [l/s]. Dam is 268 [mm] high and has two piers. Therefore the flow is three dimensional near the dam.

Fig.1 Open cannel loop with dam model

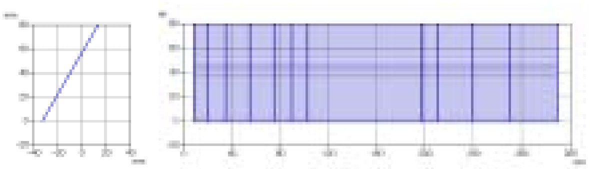


(a) ground plane



(b) front view

Fig.2 Overflow measurement system



(a) (b)

Fig.3 Cross section of measurement field in a single transducer measurement, (a) is view of x-z plane, (b) is view of y-z plane

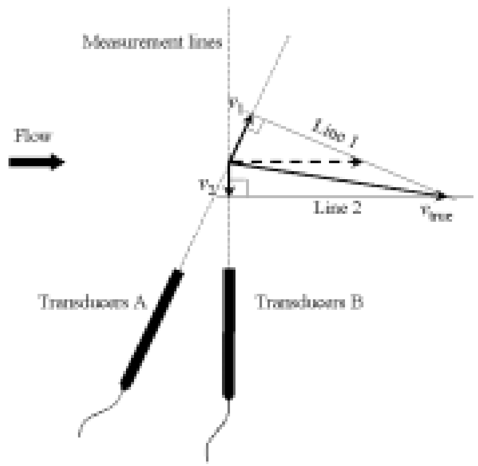


Fig.4 Velocity vector at cross point

In this study, flow rate was measured by UdFlow in pipe flow (TEST SECTION 1) and by UVP-DUO at overflow beyond the dam (TEST SECTION 2).

TEST SECTION 1 UdFlow was developed by Tokyo Electric Power Company for measurement of flow rate in a pipe. Its uncertainty has been approved to be less than 1% [5]. Therefore, the measured flow rate by TEST SECTION 1 was used to be a reference value to compare with the results of TEST SECTION 2. A transducer was fixed on the pipe at 8 degrees to vertical line on outside surface. The basic frequency was 2 [MHz]. Entrained bubble was used for reflecting particles. Sampling time was 300 [msec] and the number of profiles recorded was 1024 (Measuring time was about 5 minute). Their profiles were averaged at each point for calculating flow rate.

TEST SECTION 2 UVP-DUO (Met-Flow, Lausanne) can perform multiple line measurement for vector velocity mapping on flow field. Overflow measurement system is shown in Fig.2. (a) is a ground plan and (b) is a front view. The coordinate is set that zero point is an intersection point on the dam and the side wall, x direction is a flow direction, y direction is a spanwise direction and z direction is a vertical direction. Two transducers (No.1 and No.2) were located in the open channel for measurement of x and z velocity components (v_x and v_z). Transducer No.3 was set outside of the side wall to measure y component (v_y). The basic frequency was 2 [MHz]. Transducer No.1 could be rotated in x-z plane for stepping motor. Transducer No.2 was fixed on a shaft. No.1 and 2 were set to parallel and could be traversed to y direction by a sliding motor. The unit was controlled automatically by computer. Transducer No.3 was moved manually on the side wall.

For most simple measurement of flow field using UVP, a single transducer (Transducer No.1) was used. It was inclined at 29.8 degrees to vertical line. Data were collected at twelve lines to y direction between y=0 to 320 [mm]. However lines were avoided near the pier between y=110 to 190 [mm]. Furthermore flow was assumed to be symmetric to the center of width. A cross section of measurement field is shown as Fig.3. Sampling time was 150 [msec] for one profile. The number of profiles collected was 512. Their velocity distributions were converted to v_x and averaged. Flow rate was estimated using the average profile.

Vector measurement of flow field was carried out using three transducers (Transducer No.1, No.2 and No.3). Vector is calculated at a cross point of three profiles. The configuration of vector measurement using two transducers is illustrated in Fig.4. Transducer A obtains v_1 at a cross point of measurement lines. The v_{true} appears on the Line 1, similarly, appears on the Line 2 by obtained v_2. Therefore the v_{true} is estimated as 2D vector from the cross point of measurement lines to the cross point of Line 1 and Line 2. Moreover using another transducer, vector is taken as three components.

Data were collected each cross point that was set the fifteen lines to y direction between y=0 to 320 [mm] at a cross section of y=-50 [mm] (above Transducer No.2) and the interval of 10 [mm] from z=-10 [mm] to z direction. Sampling time was 450 [msec] for a profile. The number of profiles collected was 512. Vector was calculated and averaged at each point. Flow rate was estimated using the average profile.

RESULTS AND DISCUSSION

Flow rate was set for three cases (Case1, 2 and 3). These were measured at TEST SECTION 1 and 2.

Results of TEST SECTION 1

Results are summarized in Table.1. Reynolds number for all cases is larger than 10^4 and in turbulent flow in the pipe.

Results of TEST SECTION 2

A measured velocity distribution using Transducer No.1 is shown in Fig.5 (Case3). The horizontal axis is distance from transducer and the vertical axis is velocity. Error bar is standard deviation of averaging. The transducer was located at y=310 [mm] with inclination angle of 21.3 degrees. A free surface must appear on a velocity distribution because it was measured from inside of water. We took a following way to determine the location of free surface. Velocity increases from the transducer to near the dam and then it decreases. Large fluctuation appears at about 160[mm]. It was checked that this point corresponds to the free surface by a scale. In this study, the location of free surface was determined by a large fluctuation on the average velocity distribution.

The velocity distribution by a single transducer measurement is shown in Fig.6 (a), (b) and (c) for Case1, Case2 and Case3 respectively. The horizontal and vertical axes are y and z. The shaded rectangular shows area of no data near the pier. Magnitude of velocity is shown by colors.

In Case1, the velocity is lower near the pier and free surface and higher near the dam. Furthermore the depth of water is out of the horizontal. Other cases also indicate a similar tendency. Usual measurement techniques assume that the depth of water is fixed and a flow is steady for y direction. But in the actual conditions, this assumption must not be valid. Therefore it is necessary for accurate environmental flow measurement to obtain a detailed velocity distribution. The present result indicates that UVP is a more powerful measurement method than others.

Velocity vector as a result of the three transducers measurement in case3 is shown in Fig.7 (a), (b) and (c). (a) is the horizontal plan, (b) is the side view and (c) is the front view. Arrows and colors give velocity vectors. It shows that the flow diverges as escaping from the pier and the dam. Comparatively fast flow appears near the free surface. This is different from the results of a single transducer measurement. In a single transducer measurement, a v_x calculated is given as an arrow of broken line in Fig.4. Therefore it occurred that the v_x is different from the v_{true}.

Table.1 Flow rate in a pipe

	Case1	Case2	Case3
Q_{pipe}[l/s]	8.5	14.0	21.1
Standard deviation [l/s]	1.0	1.1	1.6
Re	$4.80*10^4$	$7.62*10^4$	$1.08*10^5$

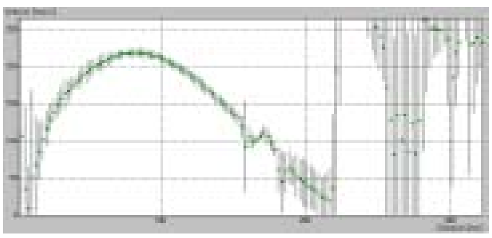
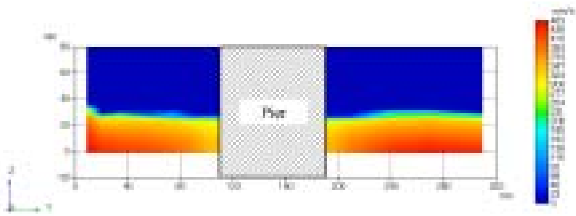
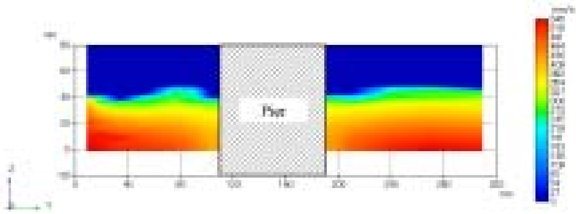


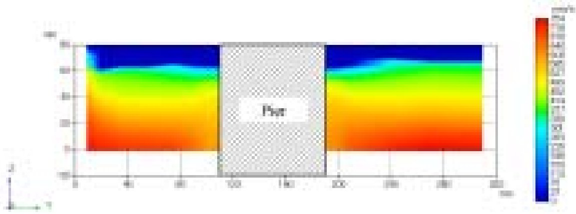
Fig.5 Velocity distribution using Transducer No.1



(a) in Case1 (Q_{pipe} is 8.5 [l/s])

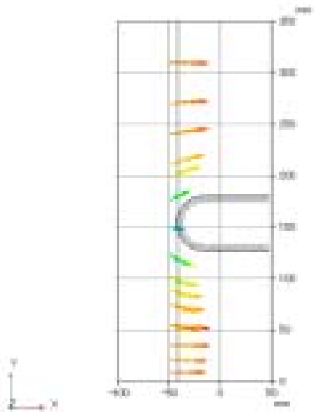


(b) in Case2 (Q_{pipe} is 14.0 [l/s])

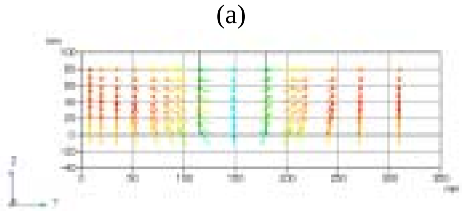


(c) in Case3 (Q_{pipe} is 21.1 [l/s])

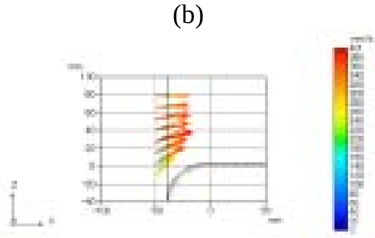
Fig.6 Velocity distribution of flow field in a single transducer measurement



(a)



(b)



(c)

Fig.7 Velocity vector on a cross section of flow field in the three transducers measurement, (a) is the horizontal plan, (b) is the side view and (c) is the front view

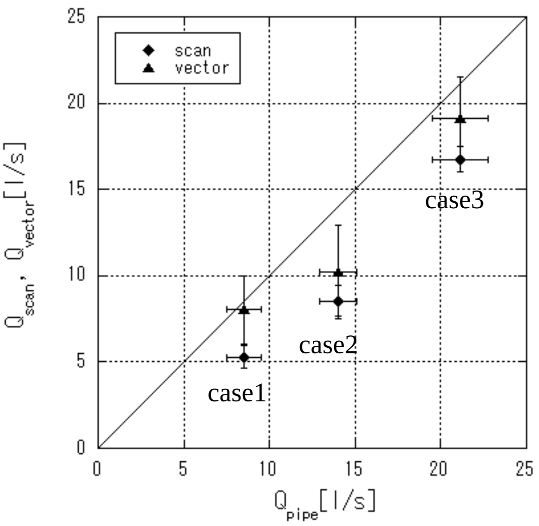


Fig.8 In comparison with Q_{scan} and Q_{vector} to Q_{pipe}

In order to make a quantitative comparison, flow rate was estimated from the measured velocity distribution. Q_{scan} is a flow rate from a single transducer measurement. Q_{vector} is a flow rate estimated from the three transducers measurement. Results are plotted in Fig.8. The horizontal axis is Q_{pipe} and the vertical axis is in Q_{scan} and Q_{vector}. Error bar is a standard deviation for each axis. In all cases Q_{vector} is closer to the diagonal line than Q_{scan}. Especially, a good agreement was attained in case1 and case3. A one dimensional flow cannot be assumed since the flow had three dimensional components in consequence of pier and dam. Therefore, Q_{vector} from a more detailed measurement is better than Q_{scan}.

CONCLUDING REMARKS

In this study, velocity vector was measured in an open channel flow field near the dam model. Flow rate was estimated using the vector flow fields. Furthermore, applicability for environmental flow measurement was evaluated at qualitatively and quantitatively.

It is concluded that UVP is powerful technique for quantitative or qualitative measurement of environmental flow. When flow cannot be assumed as a one dimensional flow, measurement has to be made for velocity vector by multiple transducers.

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