A NEW METHOD FOR MEASURING THREE-DIMENSIONAL FLOW STRUCTURES AROUND RIVER BANK USING ADCP

Masaru Koshiishi[1], Tatsuhiko Uchida[2] and Shoji Fukuoka[3]

ABSTRACT

Detailed mapping of velocity using Acoustic Doppler Current Profiler (ADCP) mounted on a sliding platform was carried out around a revetment in the experimental meandering channel constructed in the Jyoganji River. To measure detailed velocity distributions around revetments using ADCP, we developed a new method to improve the low spatial resolution of the conventional method by using individual beam data of different directions. We demonstrated the accuracy of the new method through the comparison with velocity distributions measured by the Electromagnetic Current Meter (ECM) in the Asa River. Results indicated that the new method was reliable to understand three dimensional flow structures in flow attacking zones with steep velocity gradients and local scouring around revetments.

1.   INTRODUCTION

Revetments are constructed to protect the bank against the erosion. However, they also tend to cause severe bed scouring along revetments (Osada *et al.*, 2007). One of the authors has developed nature friendly bank protection works using natural bars protected with large stones in flow attacking areas of the Jyoganji River (Fujimoto *et al.*, 2010). It is necessary for a reliable bank protection, not only to reveal flow structures around river constructions, but also to develop a calculation method that can reproduce these flows. Uchida and Fukuoka (2012) proposed a new depth integrated model that calculates three-dimensional flow structures by using depth integrated vorticity equations without the assumption of the shallow water flow. However, very few data of detailed velocity distributions in actual flood scale flows have been measured for the validity check of models and understanding three-dimensional flow structures. For example, because of large hydrodynamic forces acting on the probe of an anemometer at deep water or high velocity conditions, it is difficult to measure velocity distributions in flows attacking on revetments by an anemometer which measures by means of a single point such as an ECM. Recent advancements in ADCP measuring vertical velocity distributions from the water surface have provided the means for measuring flood discharge and velocity distributions (Nihei *et al.*, 2008). But some studies have revealed that measuring errors could be seen in the steep bank of the cross-section, because the ADCP measurements are conducted

[1] Graduate Student, Graduate School of Science and Engineering, Chuo University,
1-13-27 Kasuga, Bunkyo-ku, Tokyo, Japan, 1-13-27 (masaru-k@civil.chuo-u.ac.jp)
[2] Associate Professor, Research and Development Initiative, Chuo University,
1-13-27 Kasuga, Bunkyo-ku, Tokyo, Japan, 1-13-27 (utida@tamacc.chuo-u.ac.jp)
[3] Professor, Research and Development Initiative, Chuo University,
1-13-27 Kasuga, Bunkyo-ku, Tokyo, Japan, 1-13-27 (sfuku@tamacc.chuo-u.ac.jp)

by averaged beam data from four transducers in different directions (Nihei *et al.*, 2008, Gunawan *et al.*, 2010). On the other hand, Detert *et al.* (2008) presented fairly good results in vertical distributions of streamwise velocity which are calculated by one beam data (1D-ADCP) in the rectangular experimental channel. This follows that the spatial error caused by averaged individual beam data from four transducers of different directions reduces the accuracy of measuring results collected by ADCP.

This paper proposes a new method for measuring velocity distributions in flow attacking areas by using ADCP. We investigate the accuracy of the new method through the comparison with velocity distributions measured by the ECM in the Asa River. This paper also presents the structure of the 3D flow attacking a revetment in the field experiment with actual floods scale.

2. A NEW METHOD FOR MEASURING THREE-DIMENSIONAL FLOW STRUCTURES USING ADCP
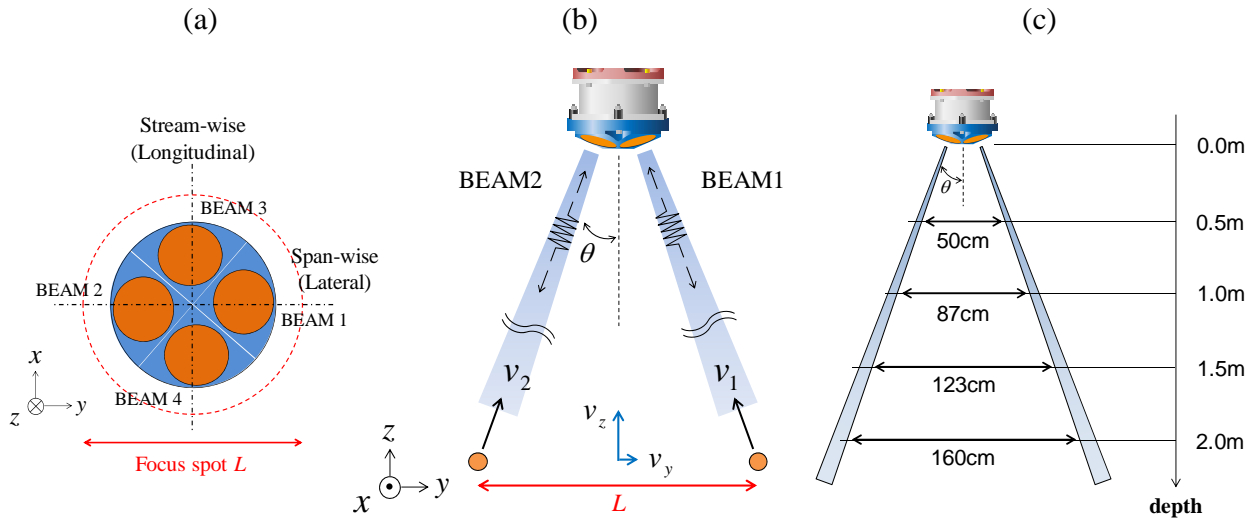

Figure 1 Calculation of velocity with ADCP beams and Focus spot *L*.

ADCP method has been used for the measurement of three dimensional velocity distributions using Doppler shift (Teledyne RD Instruments, 2006). Figures 1 (a) and (b) show the definition of each beam direction and span-wise (lateral) sectional view, respectively. The conventional ADCP method gives longitudinal, lateral and vertical velocities v_x, v_y, v_z in equation (1) by using four individual beam data v_1 - v_4 with an assumption of constant velocity in the focus spot *L* (Fig. 1).

$$v_x = \frac{-v_3 + v_4}{2\sin\theta}, \quad v_y = \frac{-v_1 + v_2}{2\sin\theta}, \quad v_z = \left(\frac{v_1 + v_2}{2\cos\theta} + \frac{v_3 + v_4}{2\cos\theta}\right)/2 \tag{1}$$

However, the conventional method cannot give accurate velocity distributions of flows with local velocity gradients and deep water depth, because of velocity variations within the focus spot *L* that expand towards the vertical direction by the angle of 20 degrees as shown in Fig. 1 (c).

In this paper, it is assumed that variations of stream-wise velocity component v_x in the focus spot *L* are negligibly-small compared with those of the lateral and vertical direction. Thus, only the stream-wise velocity v_x is calculated by equation (1) with the assumption of constant velocity in the focus spot *L*. But, lateral and vertical velocity at any point are calculated by equation (2) using

superimposing spatially-interpolated individual beam data v_1 , v_2 which are measured continuously in lateral direction and averaged over time (Fig. 2).

$$v_y = \frac{-v_{1in} + v_{2in}}{2\sin\theta}, \quad v_z = \frac{v_{1in} + v_{2in}}{2\cos\theta} \tag{2}$$

Here, v_{1in}: interpolated v_1, v_{2in}: interpolated v_2. For the above method, we introduce the assumption of little variation in mean velocity during the measurement. The measurement should be conducted with the appropriate sampling time and space for averaging procedure.
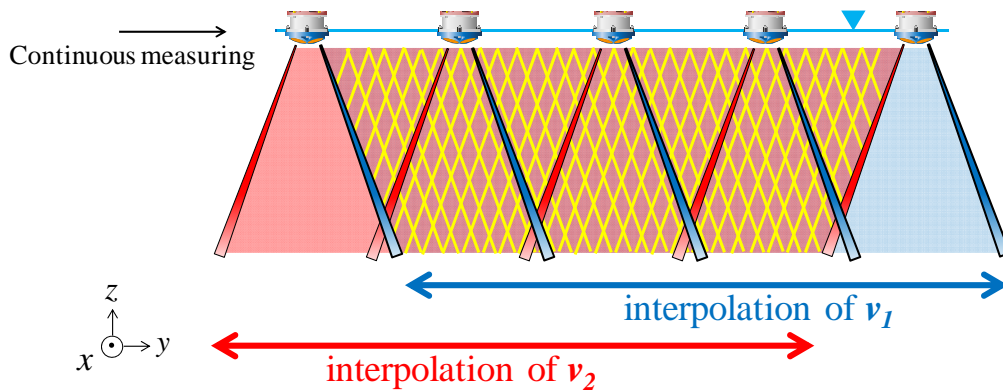
Figure 2 Concept of the new method.

Where one of the beam data cannot be obtained such as near wall or bed, velocity can be calculated by the others three beam data (Teledyne RD Instruments, 2006). Also, in this case, the new ADCP method will lead to an increase in the precision of velocity calculation compared to the conventional ADCP method by using three available beams directly.

3. APPLICATION TO THREE-DIMENSIONAL FLOW FIELD IN THE ASA RIVER AND VALIDATION OF THE NEW METHOD

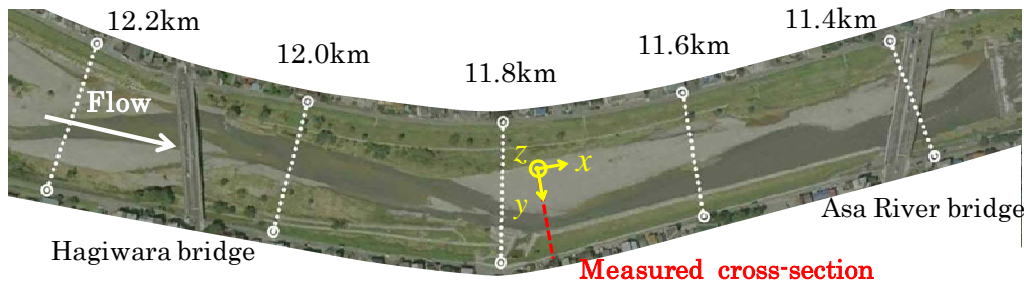### 3.1 Summary of Field Observation in the Asa River

Figure 3 Location of the observed site in the Asa River.

The field measurement was carried out at the flow attacking zone along right bank located in the vicinity of 11.75km of the Asa River (Fig. 3). The low-water channel in the experimental field is curved and has revetment works with a gradual slope (Fig. 4).
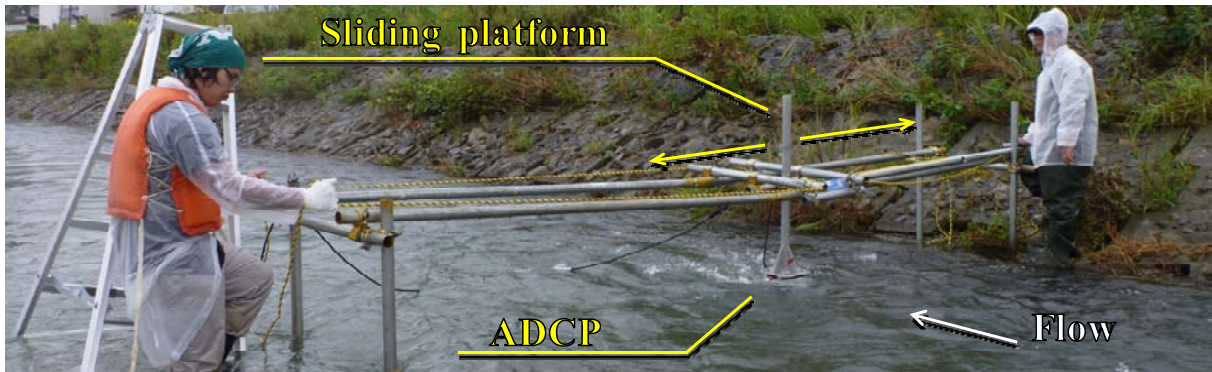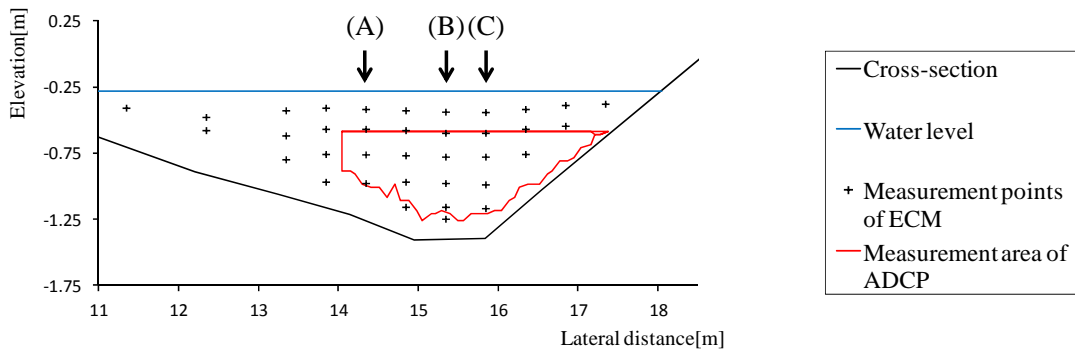
Figure 4 Picture of the observation.

Figure 5 Measurement area and points by ADCP and ECM.

Hydraulic conditions during the velocity measurement were mean depth: 0.55m, water surface width: 9.13m, mean velocity: 0.37m/s and discharge: 1.86m^3/s. The observation was conducted using a Workhorse ADCP Rio Grande manufactured by RD Instruments, Inc. and two-dimensional Electromagnetic Current Meter, AEM213-D manufactured by JFE Advantech Co., Ltd. Velocity data within the red line as shown in Fig. 5 were collected by using ADCP mounted on the sliding platform as shown in Fig. 4 (time constant: 10.0s, cross-sectional interval: 0.1m). Black Cross-points in Fig. 5 show measurement points by using ECM (time constant: 30.0s, cross-sectional interval: 0.5m).

3.2 Comparisons of the Measurement Results between the Conventional Method and the New Method

Figures 6 and 7 show measured results by the ECM, the conventional ADCP method and the new ADCP method in the Asa River. Figure 6 shows distributions of primary flow contours and secondary flow vectors. Secondary flow vectors by the ECM show only the *y*-component because the instrument is 2-dimensional (*x*-*y*) type. Both ADCP results give similar results to the ECM in that the maximum velocity region of the primary flow occurs along the right bank. But, in the secondary flow, the new method presents better results compared with that of the conventional method. Vertical distributions of longitudinal and lateral direction velocities v_x, v_y are compared in Fig. 7. Points (A), (B), (C) are shown in Fig. 5. Lateral velocity distributions by the new method provide good agreement with that by the ECM compared with the conventional method. Especially in the deep portion of water depth, the new method makes it possible to measure detailed lateral velocity distributions.
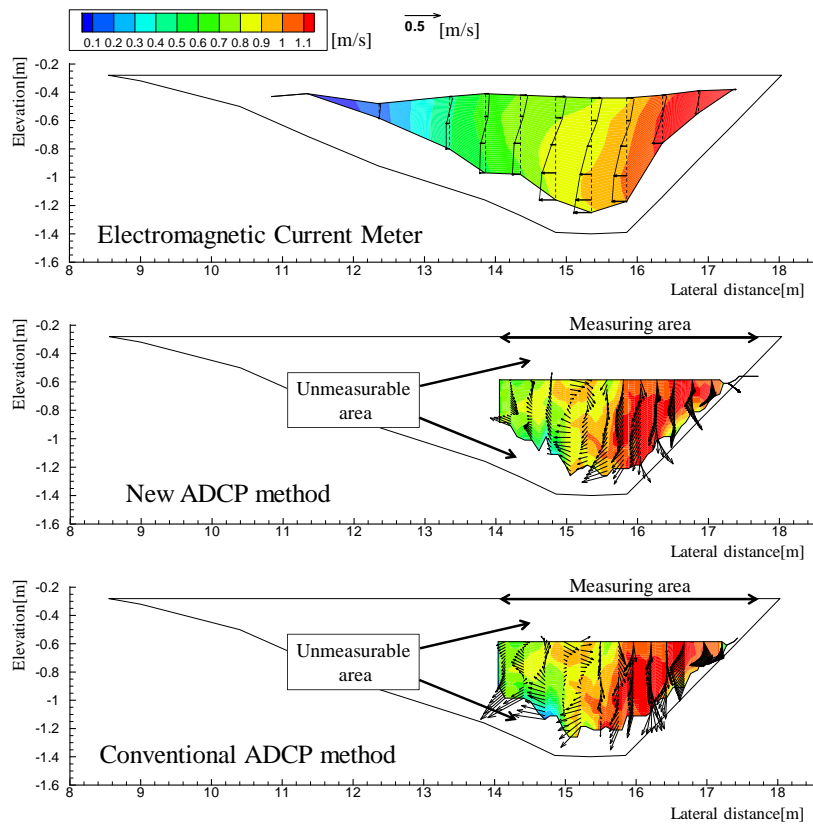
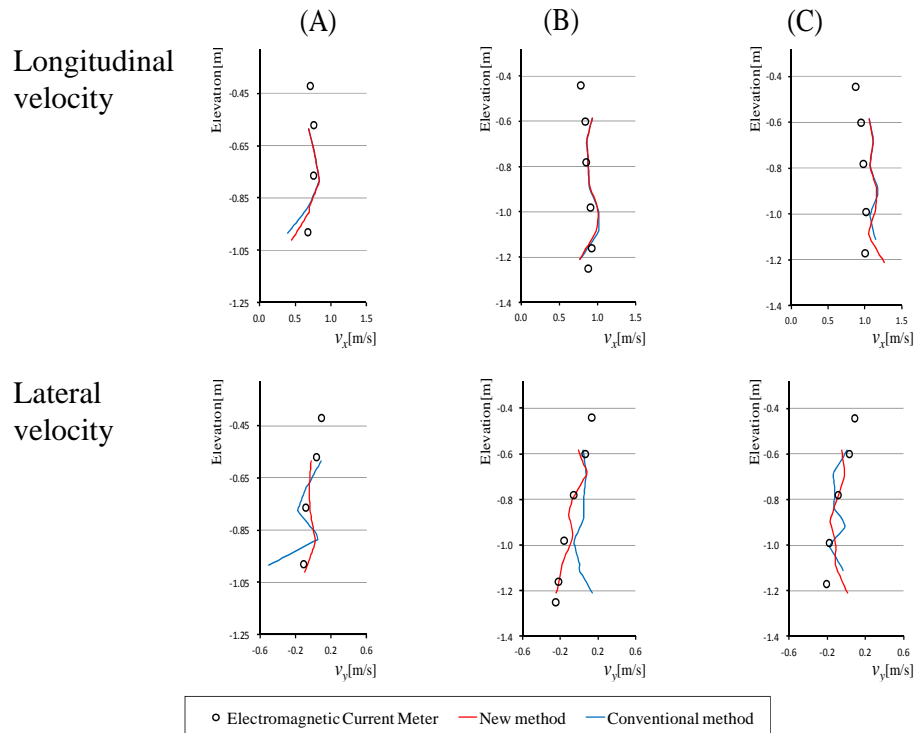Figure 6 Contours of longitudinal velocity and vectors of lateral velocity.

Figure 7 Comparisons of longitudinal velocity v_x and lateral velocity v_y.

4.   APPLICATION TO MEASURED VELOCITY DISTRIBUTION IN THE JYOGANJI RIVER

4.1   Summary of the Field Experiment in the Jyoganji River

The field experiment in the Jyoganji River in 2011 had a twofold purpose. One was to investigate characteristics of erosion and bed scouring beside revetment works (Koikeda *et al.*, 2012). The other was to obtain the detailed data for validating the new depth integrated calculation method for bed scouring in flow attacking area. Figure 8 shows plan view of the experimental meandering channel. The experiments were conducted in a compound meandering channel, and the configurations are total channel length: 170.0m, total channel width: 20.0m, main channel width: 4.0m, main channel depth: 1.0m and bed slope: 1/200. There are vertical revetments made with concrete wall in two flow attacking zones around meandering sections (Fig. 8, 9). We conducted the experiments in ascending order of discharges, about 7.0m^3/s (exp1), 7.6m^3/s (exp2), 13.7m^3/s (exp3).
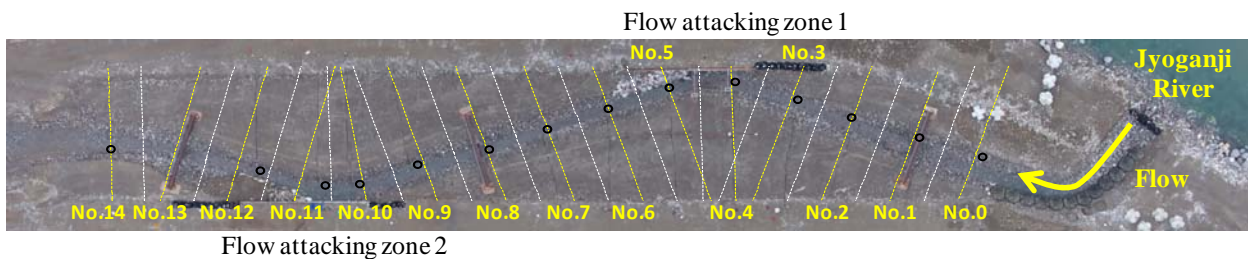

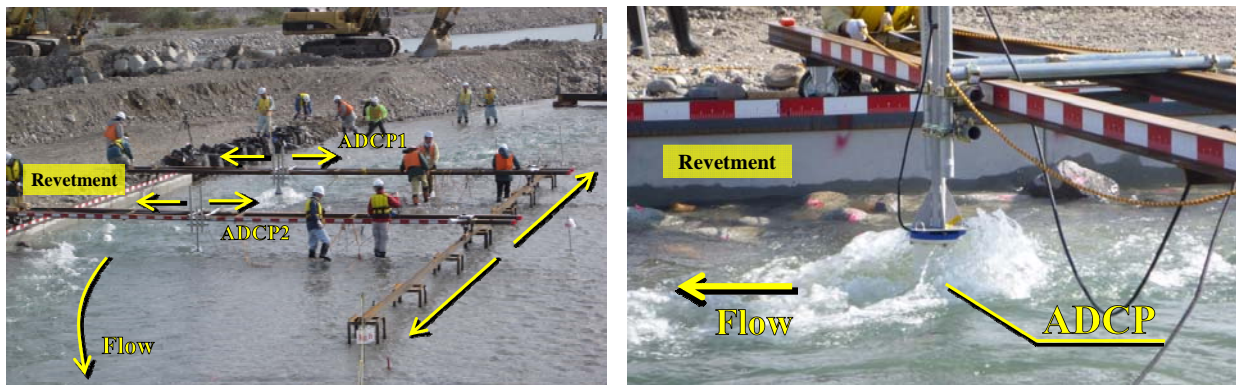Figure 8 Plan view of the experimental channel in the Jyoganji River.

Figure 9 Picture of the velocity measurement on flow attacking zone 1.

Fig. 10 shows cross-sectional form changes and water level around flow attacking zones 1, 2 in each case. Natural bars with large stones were prepared in the flow attacking zone 1 before the experiment. And, velocity measurements were conducted around the zone 1 under the condition of little change in cross-sectional form as shown at No.5 station of Fig. 10. In the flow attacking zone 2, natural bars without large stones were arranged at first, and large stones with restored bars were arranged after exp. 1 (Fig. 10 No. 11). It aimed for investigating characteristics of erosion and bed scouring around the revetment. As a result, Koikeda *et al.* (2012) reported that bar erosion in a broad scale was developed around bars (Fig. 10 No. 11). For this reason, flow attacking zone 1 is protected against erosion and bed scouring by large stones, but there are large hydrodynamic forces caused. Fig. 9 shows a picture of velocity measurements.
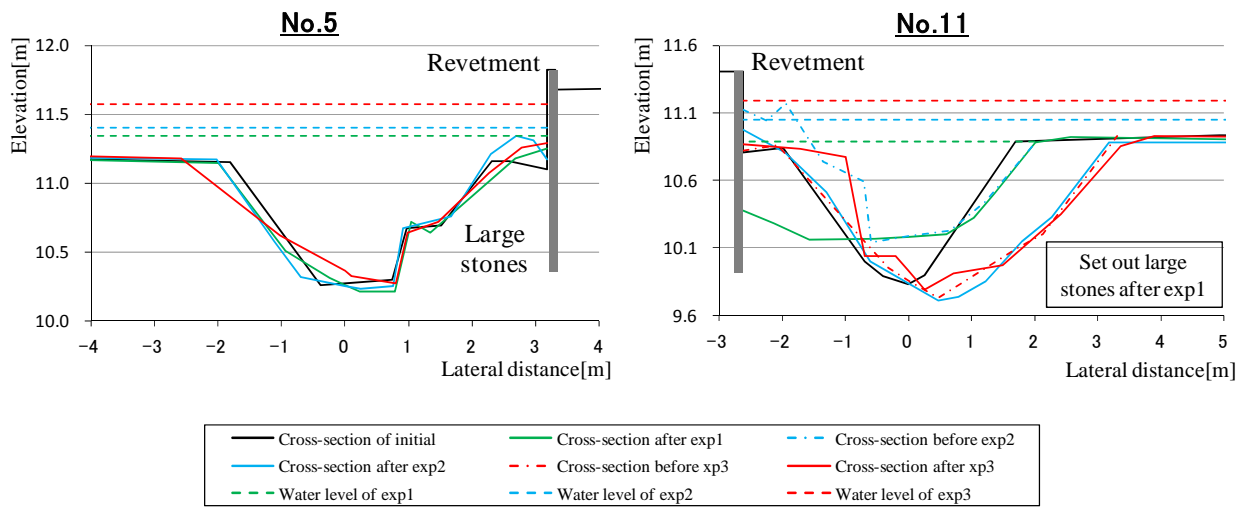
Figure 10 Cross-sectional form changes on flow attacking zones 1, 2.

Velocity data were measured by using ADCP mounted on the sliding rail at cross-sections a-g as shown in Fig. 11. The draft of the ADCP was a little deep for cutting down effects of bubble, because there are hard flow conditions with high velocity in contrast with observation in the Asa River as shown in Fig. 12. Therefore, velocity data couldn't be collected in the range of about 0.4m depth from water surface. In the cross-sections c and e, velocity data to 0.15m from water surface are measured by using the ECM for interpolating. Instruments were same as the Asa River observation.

4.2   Measurement Results in the Flow attacking zone 1 at exp2

In Fig. 11, black vector and red vector show bottom velocity by the new ADCP method and surface velocity by the ECM, respectively. The bottom velocity is defined as averaged velocity around 80 percent of depth. Surface velocity is measurement value of the ECM at 0.15m from surface.
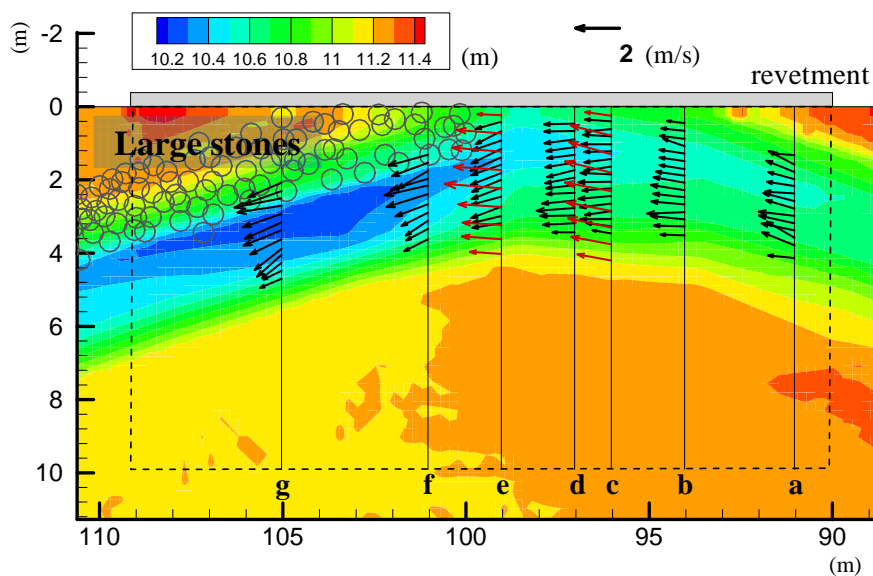

Figure 11 Surface (red) and bottom (black) velocity on flow attacking zone 1 of exp2.

Bottom velocity along the inner bank of the main channel is high between cross-section a and d. Secondary flow can be seen around cross-section c and e, in which surface velocity and bottom velocity are towards the right bank and inner bank, respectively.
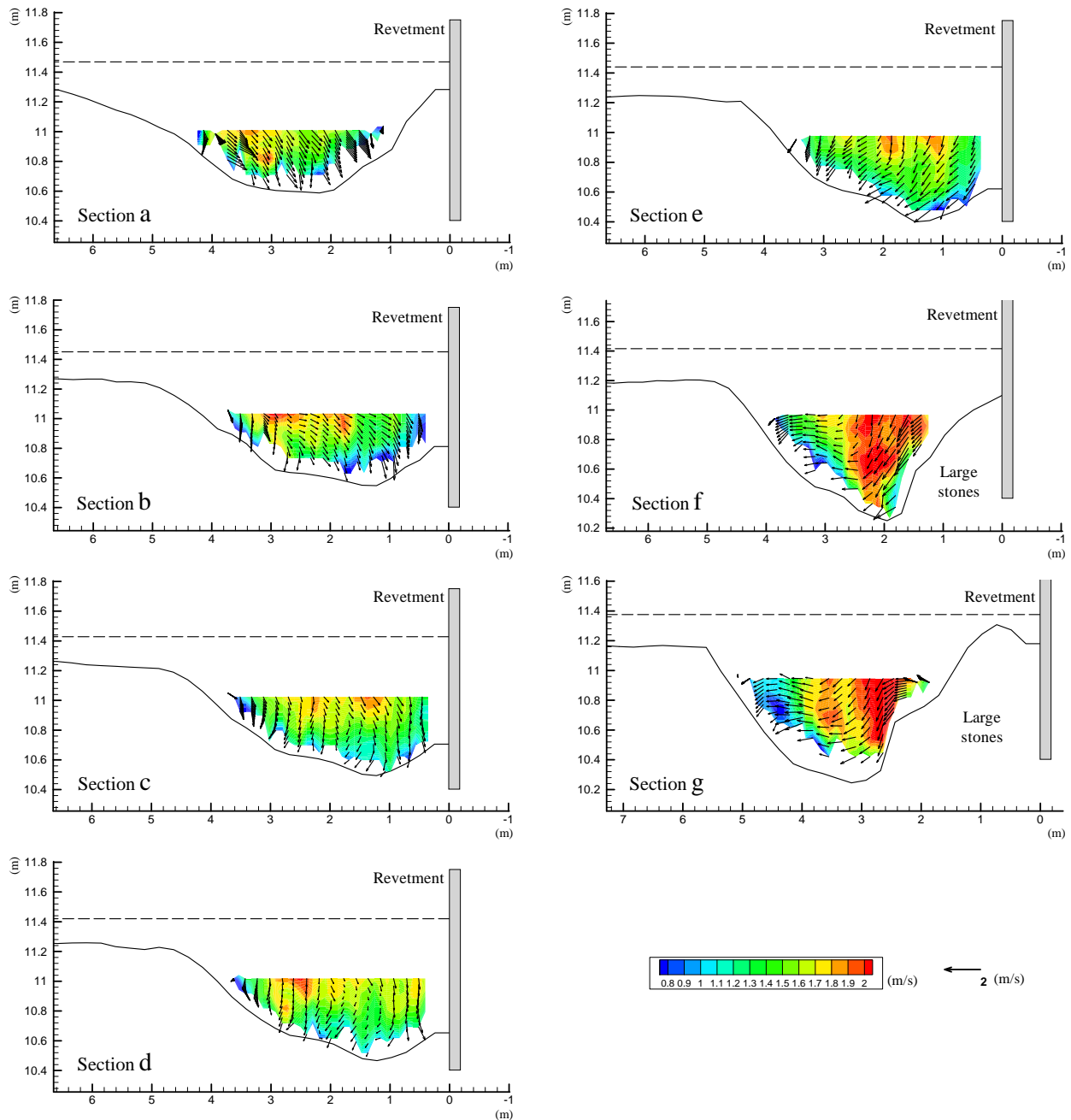

Figure 12 Velocity distributions on flow attacking zone 1 of exp2.

Fig. 12 shows vertical velocity distributions of primary flow as contour and secondary flow as vector by the new ADCP method. With regard to primary flow, high velocity regions are occurred along the inner bank between cross-section a and b. Their regions gradually shift towards the right bank between cross-section c and g. In the cross-section f and g, high velocity regions occur near the bottom. The reason for this is that the secondary flow beside revetments along right bank transports momentum of primary flow from surface of the inner bank to bottom of the right bank. The above

also induces the result that bottom velocity, which plays important role in the sediment transport, is accelerated beside revetments with small friction. Furthermore, the flows become concentrated more severely as bank erosion and bed scouring develop by the process.

5   CONCLUSIONS

The new method provides fairly good measuring results in flow attacking zones compared with the previous method by ADCP. Especially in the portion of maximum scouring area around a revetment with the considerable erosion and scouring energy where the previous method could not be applied, the measuring method makes it possible to measure detailed distributions of three dimensional flows. Furthermore, this paper supplies detailed data of velocity distributions in flow attacking zones by the field experiment in the Jyoganji River. Experiments proved that the new method is reliable to understand three dimensional flow structures in concentrated zones with local scouring in a meandering channel.

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