Water Discharge Measurements with ADCP in High Speed Flow with High Sediment Concentration

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The authors conducted water discharge measurement at one of the representative super flashy rivers in Japan, which has high speed water velocity, as well as high turbidity condition during flooding. Because of this characteristic, very active river bed evolution takes place. To determine the water discharge value, the ADCP, RTK-GPS, echo sounder mounted on the tethered high speed river boat were employed. Because of adverse measurement condition for acoustic type devices, existing algorism to determine the river bed is not applicable. The authors in this paper explain about the problem, and new algorism to estimate the river bed from low quality ADCP data. With the ADCP data and the new algorism, hydraulic phenomena during flooding appeared as actively changed river bed elevation. In addition, authors explain about how the river bed evolution affects to the water discharge values.

Keywords: ADCP, riverbed elevation changes, high speed flow, high turbidity flow, water discharge measurement

1 INTRODUCTION

Some of Japanese rivers are classified as flashy stream compared with others on the continents since river bed slope is steep, length of river channel is short, as well as water discharge at the normal stage is very low compared with it during flood events. Because of that, water velocity is very rapid and water surface vibrates violently during a flood event. Therefore, hydraulic phenomena underneath of water in actual rivers have been considered as unknown by most of river engineers. On the other hand, an acoustic Doppler current profiler (ADCP), which was originally developed as a measurement device for marine measurement research, has been applied to the actual rivers. For example, United States Geological Survey (USGS) summarized essence of ADCP measurement in the rivers [1]. In the case of Japan, starting from Kinoshita et al [2], the number of observational cases has increased recently. Especially with help of recent development of peripheral devices; e.g., the high speed river boat and etc, many ADCP observation have conducted in extreme condition in terms of severe weather, as well as high speed river velocity [3][4].

The Hime River, which is one of the representative super flashy river in Japan, has a river bed slope of about 1/120 within the river reach operated by the central government. Because of many landslides occurred at the upper or the middle part of the catchment area, considerable amount of sediment supplies have been recognized. Therefore, the river condition during flood events involve rapid velocity, high turbidity, as well as very active river bed evolution. Actually, at the one of the largest flood events in 1995, large difference was indicated between water discharge observed by the float method and estimated by the rainfall runoff model. This is one of the examples showing the difficulty of water discharge measurement, where river bed evolution frequently occurs.

To understand the difference between observation and estimation, and mechanism of actual phenomena, the authors conducted the water discharge measurement with ADCP; Work Horse ADCP (1200kHz) manufacture by Teledyne RD instruments, Real Time Kinematic Global Positioning System (RTK-GPS) or Differential GPS, and echo sounder with 200 kHz mounted on tethered boat; High Speed River Boat. In addition, the radio type non-contact current meter was applied to measure the water surface velocity. We experienced floods, whose size are about a thousand cubic meters per seconds, as well as several hundred cubic meter per seconds. In the measurements, the authors encountered problem associated with the bathymetry measurement by the echo sounder, because of high turbidity, as well as stable positioning of GPS due to splashed water on the GPS antenna. Regarding the first problem, authors developed an algorism to identify the water depth with ADCP's back scatter profiling data. Regarding the second problem, the authors abandoned ADCP as velocity measurement devices. Instead, the authors employed the water surface velocity, measured by radio non-contact current meter as velocity values to obtain the water discharge values.

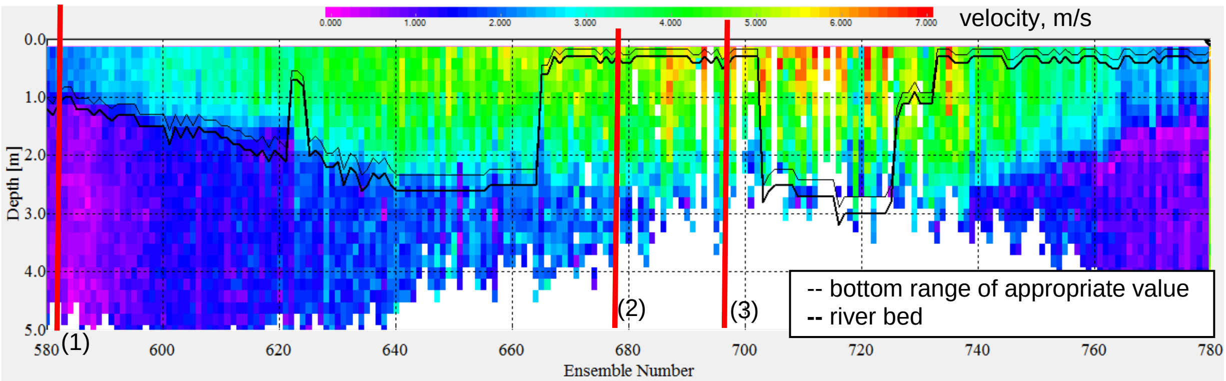
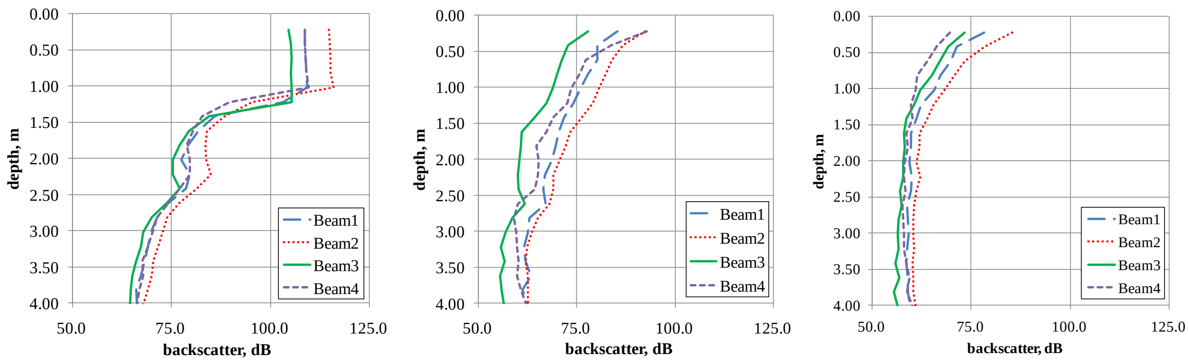


Figure 1: An example of ADCP measurement in high speed flow with high sediment concentration



(a) Section (1) (b) Section (2) (c) Section(3)

Figure 2: one of the example of backscatter profile

This paper describes about low quality values of ADCP to explain the actual problem, and the algorism to estimate the water depth, and the river bed evolution, which was actually observed. Finally we calculated the water discharge values to understand the importance of applying the river bed evolution.

2 METHOD

2.1 Problem statement

Figure 1 shows an example of ADCP measurement in high velocity/turbidity condition at the Hime river. Contours indicates the magnitude velocity between 0 and 7m/s including white indicating missing data. Lower black curve indicates the river bed obtained by the echo sounder. To illustrate Figure 1, since values calculated by three beam velocities, values below the river bed were accepted. As this figure indicates, the values obtained by the echo sounder are suspected as incorrect results, since water depths are too shallow between 660 and 680 in ensemble number as well as more than 730, though velocity values are obtained. On the other hand, in the ranges between 580 and 665 excluding the spike around 625, and between 700 and 730, the echo sounder properly provided the accurate values.

Figure 2 shows backscatter profiles obtained by each beam of ADCP at the ensemble number of 584, 680, and 695 in Figure 1. As Figure 2(a) indicates, backscatter value is about 110 dB around water surface, and keeps similar number till 1m without attenuation as beams go deeper. Moreover, they showed peak value at this point. Thereafter, they attenuated very rapidly till 70dB at 4m. This trend is one of the typical profiles obtained in fair observing condition. In practice the echo sounder as well as ADCP indicated 1.0m from this profile. Figure 2(b) indicates the backscatter value starting about 80dB around the water surface and attenuated gradually. Though it has the local maximum around 2.7m, the profile is dissimilar with that of Figure 2(a). Actually the echo sounder indicates 0.25m, whereas ADCP cannot detect the river bed. As Figure 1 shows, the indicated value of 0.25m is suspected as incorrect result since velocities obtained by ADCP are appropriate values even below the value of 0.25m. Figure 2(c) shows similar profile with that of Figure 2(b). Moreover, they simply decayed and did not have any local maximum. The example indicates that the backscatter easily attenuated in high sediment concentration condition, and that the algorism to detect the river bed is easily fails in such a flow.

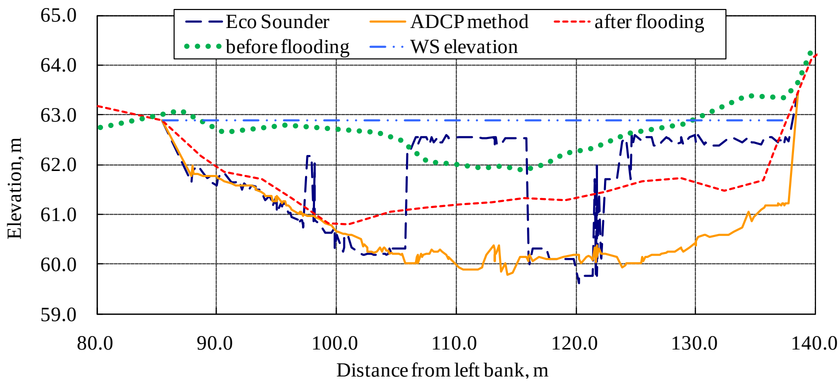


Figure 3: River bed elevation by the method and river survey before/after survey

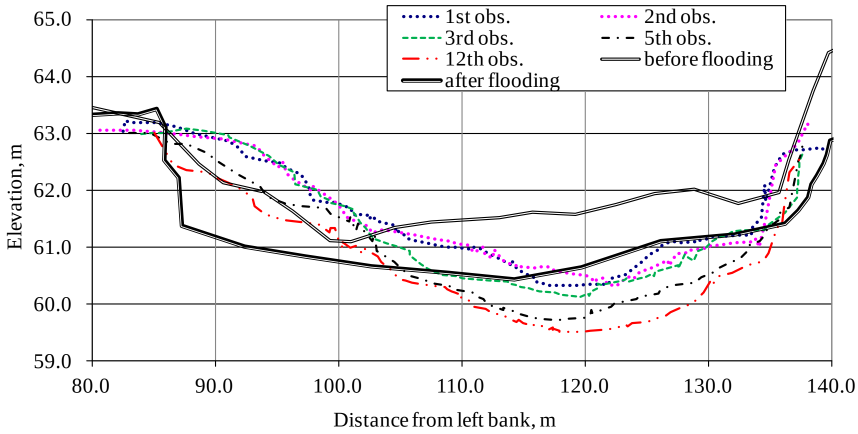


Figure 4: Time change of river bed elevation with the method

2.2 Estimation of river bed elevation

The method, which is the author's propose in this paper, is intended to estimate the river bed with the backscatter profile values obtained by ADCP with assuming water surface is flat in the cross section. Firstly, as shown in Figure 2, the vertical distribution of the backscatter examined in each ensemble. If they are similar with that of Figure 2(a), river bed can be detected as it is. If they are similar with that of Figure 2(b), the local maximum are selected and averaged. Thereafter, the averaged values are assigned as the river bed. If they are similar with that of Figure 2(c), river bed cannot be detected from this ensemble. After whole values are plotted in cross section, some ranges may or may not have an appropriate shape. In our experiences, cross sectional distribution of the river bed, most likely, included spiky noises. Therefore, with smoothing using moving average, or simply eliminating manually, appropriate river bed can be obtained, as shown in Figure 3. If there are too many ensemble similar with Figure 2(c), we need to abandon to obtain the river bed since too much missing range can be expected.

Figure 3 shows three different river beds as elevation; e.g., ADCP method explained in previous paragraph using same data of Figure 1, the echo sounder shown in Figure 1, and before/after a flood event are surveyed during normal stage. The river bed of the method shows irregularity shape in some extent, but it is continuous curve without any abrupt change. Partly it traces the values of the echo sounder. Comparison between the curves of before/after flooding indicates that the river bed elevation decreased about 2m and increased again about 1m at the point of 110m. In between 80 and 100, the method traced the one after flooding.

2.3 Calculation of water discharge values

To discuss about the effect of riverbed evolution to determination of water discharge value, three different cases were selected as shown in Table 1. Differences among those three is only the river bed elevation. Case 1 and 2 simply implement the calculation of the riverbed before/after a flood event. On the other hand, Case 3 implements the calculation based on the most recently observed river bed with ADCP. Other values, such as water

Table 1: Water discharge values with different method

Case	velocity	Velocity index	River bed elevation
1	Radio wave	0.85	Before
2	Radio wave	0.85	After
3	Radio wave	0.85	Measured by ADCP

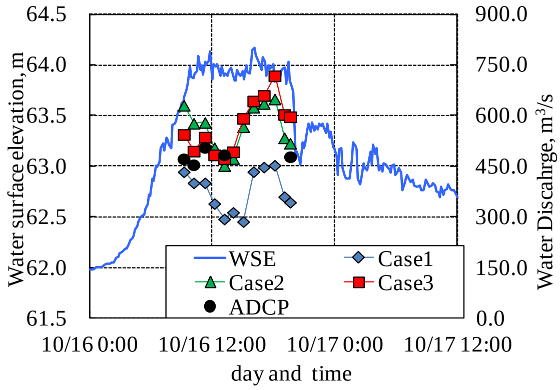


Figure 5: Time series of water discharge with different method

surface velocity as well as velocity index were commonly applied in this calculation.

3 RESULTS

For single flood events, 12 measurements were conducted, which have maximum discharge of 720m^3/s. ADCP measurements were successfully conducted in 5 measurements out of 12. Figure 4 shows river bed elevation in each measurement obtained by ADCP and estimated with the method proposed in previous chapter. In addition, the riverbed before/after a flood event are illustrated, which can be considered as initial/final shape.

As Figure 4 indicates, three points are needed to be mentioned. At Area (1); the most left area, sediment started to deposit around this area about 1m at the point of 90m; thereafter, it gradually soured till initial level at 12th observation. Finally, it scoured another 1m involving side bank erosion. At Area (2); middle of channel, river bed elevation decreased about 1m at the point of 120m. After additional 1m decreased at 12th observation, 1m deposition occurred as well. At Area (3); right river bank, starting from initial as well as 1st and 2nd observation, channel expanded till 3rd observation. At 5th observation, channel was excavated and even more deepened at 12th observation. Thereafter, river bed formed final shape as indicated. In this process, comparing geometry before and after a flood event, bank erosion of some 3m were observed.

Figure 5 shows the time series of water surface elevation as well as water discharge. Each symbol in this figure indicates the timing of measurements. Black circle indicates the timing of ADCP measurement as well. As it shows, whole measurements were conducted when water level is more than 63.5m. During this measurements, though water level almost constant, water discharge fluctuates from minimum of 470m^3/s to maximum of 720m^3/s. Water velocity cannot be explained in this paper, because of space limitation, but in practice velocity correspond to this time fluctuation of water discharge. The water discharge values obtained by the case 1 is mostly underestimated, since river bed elevation is overestimated as Figure 4 shows. At the peak discharge, underestimation of 37% is recognized assuming that of Case 3 is true. The values of Case 2 are significantly similar with that of Case 3, even though shapes of river bed are different but cross sectional area has similar values. It was unfortunate that the ADCP measurement could not be conducted between 5th and 12th observation. During this period, the river bed in the case 3 was treated as constant. However, actual discharge values increased, since velocity had increased. During this period, decreasing of the river bed, or decreasing of roughness is assumed to occur corresponding to the increasing of velocity. Those are very different phenomena in terms of estimating the discharge values. Therefore, they have to be carefully analyzed in further study.

4 CONCLUSION

The authors in this paper explained about the problem, and established new algorism to estimate the river bed from low quality ADCP data. With the ADCP data and the algorism, hydraulic phenomena during a flood event were appeared as actively changed river bed elevation. In addition, authors explained about how the river bed evolution affects to the water discharge values.

5 ACKNOWLEDGEMENT

The authors would like to thank to Mr. Inoue and Mr. Ono working at Suimon Kankyo Co., Ltd. in Japan for conducting the measurement in such an extremely difficult condition.

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