Study on Applicability of ADCP for Field-level Hydraulic Observation

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The purpose of this study is to investigate applicability of Acoustic Doppler Current Profiler (ADCP) for the field-level hydraulic observation, such as flow observation and bed configuration measurement. Hydraulic observation data, especially sand waves on the river bed, obtained during flood are crucial to make river management plan but such data are rare because of difficulty of measurement. In this situation, development of hydraulic observation method is desired. In this study, we performed hydraulic experiments, which reproduced flood conditions, using a large-scale artificial flume constructed on the floodplain of an actual river, the Tokachi River, focusing on the development of sand waves on the bed. The flume named “Chiyoda Experimental Flume” is 1,300m in length and 30 m in width, and various state-of-art observation devises can be used for measurement of hydraulic values. For the observation of sand waves under water flow, two kinds of devises, one is multi-beam sensor, and another is ADCP were used. And also the authors measured flow rate by an orthodox method, float measurement, and ADCP. In this study, the authors compared several data obtained by ADCP method and other methods to examine the applicability of ADCP.

Keywords: Large-scale experiment, hydraulic observation, sand waves, multi-beam sensor, ADCP

1 INTRODUCTION

The riverbed configuration, that is in accordance with the hydraulic conditions (e.g., water depth, flow velocity, channel width) and the bed materials, is known to affect hydraulic resistance. Numerous studies have addressed the prediction of hydraulic resistance. Most such studies have addressed form drag on a riverbed with small scale sand waves and friction drag of the riverbed surface, and prediction of the total drag. Engelund [1] introduced assumption of the general similarity of the dune formations, in which the ratio of the total energy loss and the expansion loss caused by dunes are same in the same Froude number condition, and he indicated that in flows with a similar riverbed configuration, the effective shear stress (friction drag) is an exclusive function of the total shear stress. Kishi and Kuroki [2] further studied the concept of Engelund and made the modification that the effective shear stress is a function of the total shear stress and the ratio of hydraulic radius to grain size. Yalin [3] estimated form drag by using riverbed (sand waves) form. In addition to these studies, there are many conventional experimental studies on small scale sand wave development and increases in hydraulic resistance. However, few studies have addressed the relationship between hydraulic resistance and small scale sand waves by analyzing hydraulic data or riverbed observation data from actual rivers. This is because it is difficult to take accurate, detailed measurements of bed form during floods.

The main purpose of this study is to evaluate the method to observe hydraulic values and sand waves in actual rivers. The authors used a large scale experimental flume constructed on the river course and applied Acoustic Doppler Current Profilers (ADCP) for several observation.

2 EXPERIMENTAL OUTLINES

The experiment was made using part of the Chiyoda Experimental Flume (Figure 1). The flume was built on the floodplain of the Tokachi River. With a maximum length of 1,300 m and a maximum width of 30 m, it is one of the largest experimental flumes. The configuration of the experimental flume and the locations of the measurement devices are shown in Figure 2. In this figure, measurement site locations are indicated with “P” and the three numerals following “P”. The three numerals give the distance (m) between the inflow gate and the measurement site in the flow direction. Vertical pile sheets were installed for bank protection on the left bank of the flume, and concrete armor blocks were installed on the right bank slope. The initial riverbed was a flat bed with a slope of about 1/500.

During the test, the inflow discharge was regulated by the gate. The discharge was increased gradually for the first 90 minutes after the start of the test, was kept at a constant amount for about 6 hours, and was decreased to stop in 30 minutes. The target amount of inflow rate 70m^3/s. Sediment was not supplied artificially so the bedload was provided by the flume bed itself during the test.

The water level was observed by using radar type sensors, and the velocity was observed by using floats, microwave flow meter and ADCP. The floats method was carried out at P410, and the microwave flow meters were fixed at P410 and P610. The ADCP transverse observations were made by using transverse round-trips of the observation boat at P410 and P610. The ADCP longitudinal observations were made by using longitudinal round-trips of the observation boat within the sand wave observation section (from P530 to P580). The ADCP measured the river bed elevation (e.g., sand waves) at the same time. The photo and the specification of the ADCP is shown in Figure 3 and Table 1, respectively.

To observe sand waves, a multi-beam sensor, a GPS, a direction sensor and a vibration sensor attached to the end of the arm of a power shovel were used. While the power shovel travelled on the shore along the observation section, the sensor moved in the water to measure the three-dimensional shapes of the sand waves. The data were compensated by the direction sensor, which detects directions, and the vibration sensor, which adjusts pitches, rolls, and heaves. Sand waves observations were carried out almost once an hour: from 64 minutes after the gate opened (herein after the “minute” means the past time after the gate opened.) to 471 minutes. To reduce uncertainties of the measurement caused by the vibration of the power shovel, a GPS sensor was attached together to correct altitudinal positions. The photo and the specification of the multi-beam sensor are shown in Figure 4 and Table 2, respectively.

3 EXPERIMENTAL RESULTS

3.1 Water level and discharge observation

The water level rose gradually and kept at a constant level after the inflow reached the targeted amount. The water levels observed at 211 minutes after the start, which was considered at a constant stage, are shown in Figure 5. The averaged bed elevation before and after the experiment is also shown in Figure 5.

The time series of discharge measured with floats, microwave flow meters and ADCP at P410 and P610 are shown in Figure 6 and Figure 7, respectively. The discharge was calculated from velocity multiplied by flow area in the case of the floats and the microwave flow meter. The authors used the flow areas both before and after the experiment.

3.2 Sand wave observation

Figure 8 shows the contour maps of the bed elevation measured with the multi-beam sensor at 211 minutes after the start. The legend expresses bed elevation above the sea level.

Figure 9 shows the longitudinal bed elevation measured with the multi-beam sensor and ADCP along the center line of the channel. The authors made the longitudinal bed line from the plenary data obtained with the multi-beam sensor.

4 ANALYSES

4.1 Water level and discharge

Regarding the longitudinal water level, the slope of the water surface is steep near P410, because the width of the channel becomes narrow there. The bed elevation near P410 decreased after the test because of the high velocity flow at narrow channel. However, both the water level and the bed elevation become stable near P610 because the channel width is constant there.

Next, discharge. The discharge begins to increase at 30 minutes from the start, becomes almost constant at 3hours from the start, and decreases after the gate closing at 8 hours from the start. At P410, the discharge observed with floats and the microwave sensor slightly decreases in the late stage because of the bed deformation. Therefore, the authors assume that the values calculated from the flow area before the test are probable in the early stage and the values calculated from the flow area after the test are probable in the late stage. Though the values observed with ADCP are slightly scattered especially at P410, they are not different from values observed by other methods in general. The reason for scattering at P410, the authors think, is attributed to the water surface vibration caused by the abrupt width change of the channel.

4.2 Sand wave observation

These results confirm that sand waves were generated and developed during the test. According to the time series of the contour map, the size of the waves near the pile sheets are smaller comparing to those in the center of the flume. This is attributed to the smaller flow velocities near the pile sheets.

The comparison of the bed elevation shown in Figure 9 tells that ADCP captured the characteristics of the sand wave shapes in general. (Figure 10 shows the tracking of the Multi-beam censor and the ADCP boat.) The difference, the authors assume, comes from the gaps between the longitudinal path of the ADCP boat and the center line of the channel. Figure 11 shows the difference of sand wave height, and it tells a good relationship.

5 CONCLUSIONS

The authors conducted a large-scale flow experiment with movable bed at the Chiyoda Experimental Flume, and successfully measured hydraulic values and sand waves with various sensors such as ADCP and the multi-beam sensors.

The water level observed with ADCP was reliable in the constant channel width section. Also, that was in case even in the section with abrupt channel width change.

Regarding the sand wave observation, estimated longitudinal bed configuration by using ADCP had the same characteristic as the one by using the multi-beam sensor, and the authors found that ADCP could well measure the height of the sand waves, which is one of the important factors to estimate hydraulic resistance.

Table 1: Specification of ADCP

Teledyne RD Instruments Workhorse Monitor ADCP 1200kHz	
Depth Cell Size	0.10m
Number of Depth Cells	40
Ensemble Interval	3.19sec
Water Pings	3ping

Table 2: Specification of Multi-beam sensor

Teledyne Reson SEABAT8125	
Frequency	455kHz
Along-track transmit beamwidth	1.0°
Across-track receive beamwidth	0.5°
Number of beams	240
Max swath angle	120°
Depth resolution	6mm

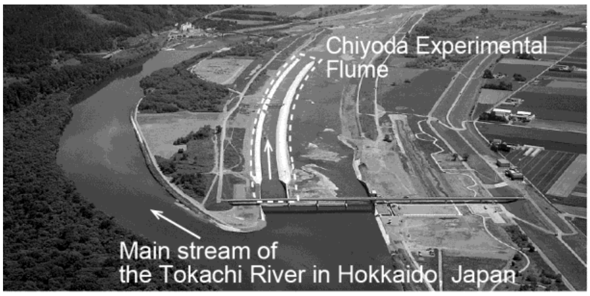

Figure 1: Aerial photo of the Chiyoda Experimental Flume

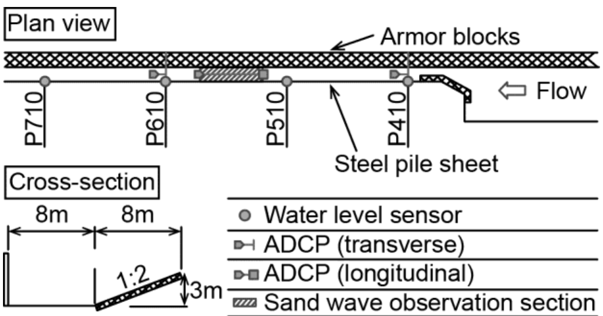

Figure 2: Shape of the flume and observation location

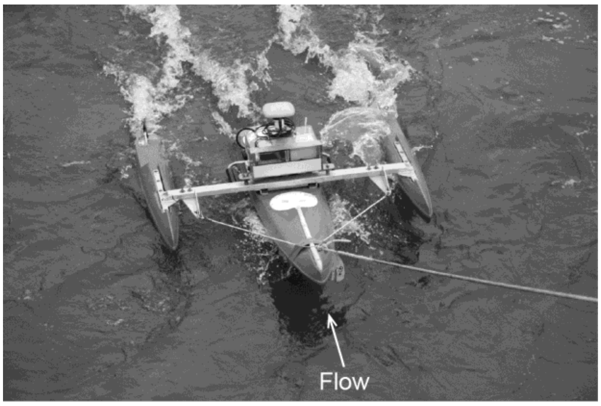

Figure 3: ADCP observation boat

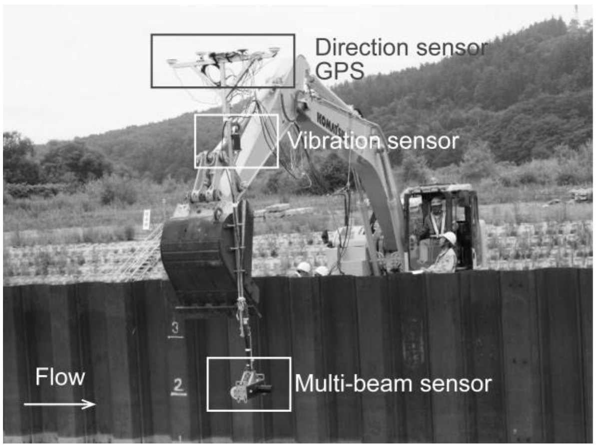

Figure 4: Sensors to observe sand waves

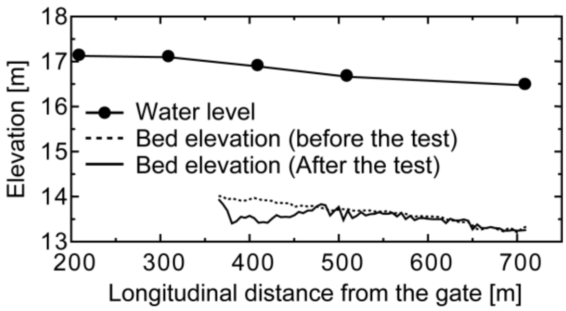

Figure 5: Longitudinal water level (211 minutes) and bed elevation (before and after the test)

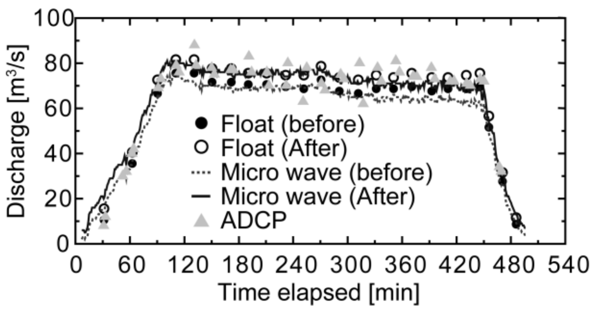

Figure 6: Time series of discharge (P410)

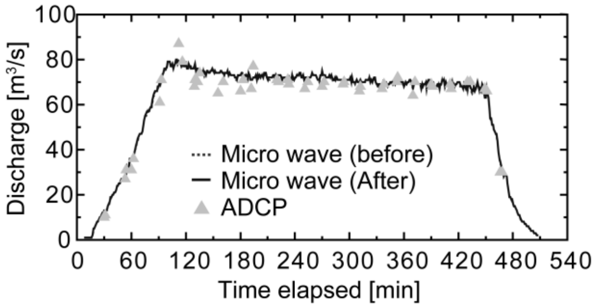

Figure 7: Time series of discharge (P610)

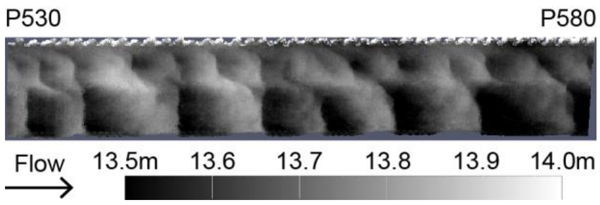

Figure 8: Sand wave contour observed with multi-beam sensor (211 minutes)

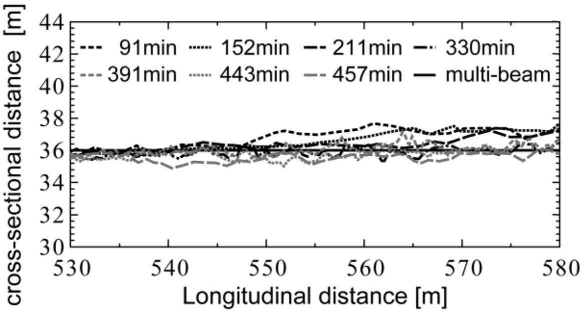

Figure 10: Tracking of the Multi-beam censor and the ADCP boat

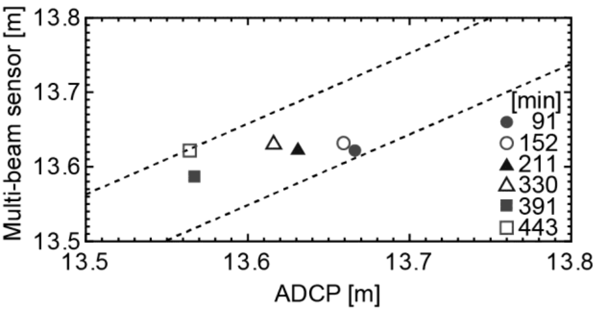

Figure 11: Comparison of sand wave height observed with multi-beam sensor and ADCP

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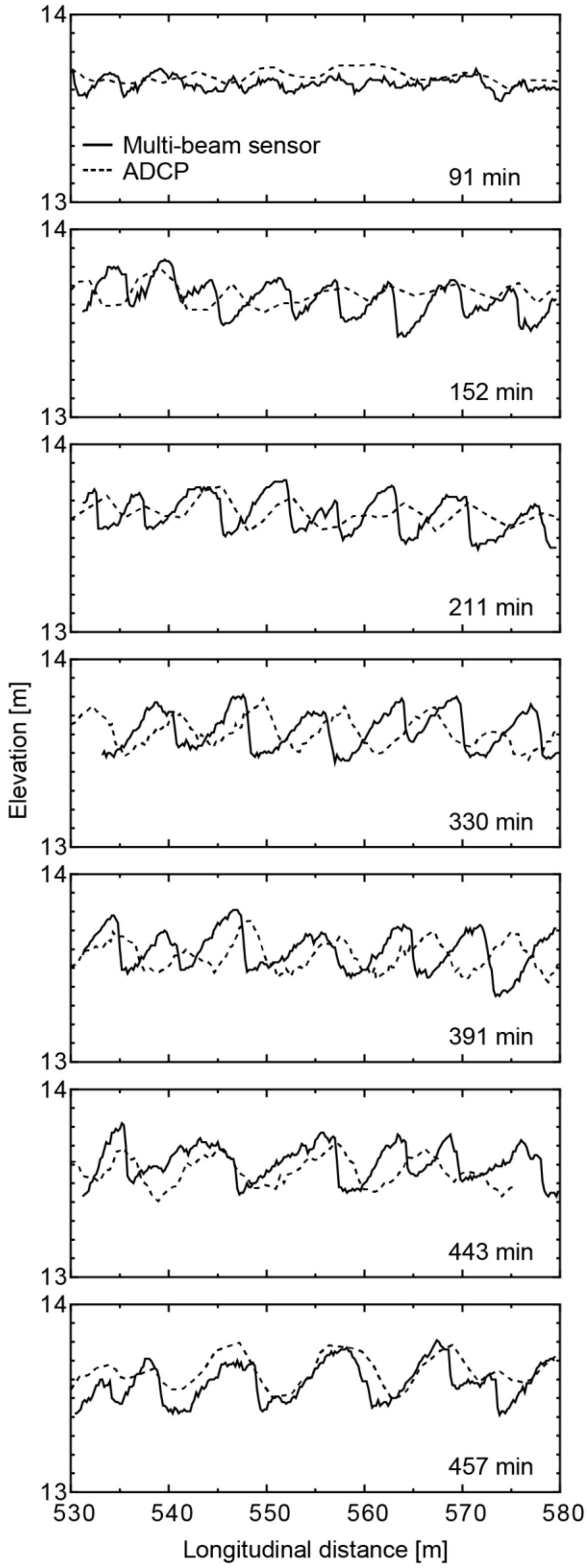

Figure 9: Comparison of bed elevation observed with multi-beam sensor and ADCP