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“Paddan” sight-seeing boat in Gothenburg
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Flow field and sediment deposition in a rectangular shallow reservoir with non symmetric inlet and outlet configuration

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UVP measurements were performed at the Laboratory of Hydraulic Constructions at EPFL in order to study the velocity flow fields developing in a rectangular shallow reservoir of adjustable length L and width B (B_{max} = 4 m, L_{max} = 6 m, inlet and outlet channel width b = 0.25 m). In fact, reservoir geometry influences the large turbulent flow structures developing in it. In particular, the results of UVP measurements in reservoirs having different locations of the inlet and outlet channel are presented. Because of the small water depth, compared to the horizontal dimensions of the reservoir, the velocity flow field can be considered in a first approximation two-dimensional; so, velocity measurements were carried out by a 2D horizontal movable square grid formed by 8 ultrasound transducers, which allowed measuring the two components of the horizontal velocity in 16 points simultaneously.

Keywords: UVP measurements, shallow reservoirs, velocity flow field, suspended sediments.

1 INTRODUCTION

The process of reservoir filling up with sediments is a serious problem questioning the sustainable use of reservoirs and which has to be considered in the optimization of sediments management. It is essential to understand which kind of flow fields can develop in a reservoir depending on its geometry that is to say on its dimensions, shape, and also on the inlet and outlet locations. In fact, flow patterns and water velocity strongly influence the sediments transport, deposition and erosion processes.

The laboratory experiments carried out focused on the schematic reference case of a rectangular shallow reservoir, endowed with free-surface rectangular inlet and outlet channels.

The present work is an extension of the experiments carried out by Kantoush [4], who started to analyze the influence of reservoir geometry on flow patterns and sediments deposition. A recently carried out study of the influence of inlet and outlet channel position on hydraulic and sedimentation is presented in this paper.

The flow field developing in the reservoir is mainly 2D, so the two components of the horizontal velocity were measured by UVP transducers (Metflow, [2]) forming a movable square grid, giving a good representation of the main large-scale eddies existing in the reservoir.

Since suspended sediments may represent for some reservoirs a big amount of the total solid load in certain flood conditions, leading to considerable deposits, tests with a constant concentration of sediments supplying were performed. Afterwards, the thickness of the resulting deposits on reservoir bottom was measured.

2 LABORATORY SET- UP

The experimental facility of the Laboratory of Hydraulic Constructions at EPFL is a rectangular shallow reservoir with a smooth horizontal bottom (Kantoush, [1]). The maximum depth is 30 cm and maximum horizontal dimensions are 6 m x 4 m. Movable PVC walls allow changing the length L and the width B of the reservoir, in the way to test different L/B ratios.

A free-surface inlet channel of fixed width b = 0.25 m and an equal outlet channel can be moved along the B side of the reservoir, giving raise to 4 configurations having different locations of the inlet and outlet channel. For the performed experiments, reservoir dimensions were fixed at L = 4.5 m and B = 4 m.

The hydraulic conditions of the tests were a discharge Q = 7 l/s and a reservoir water depth h = 0.2 m. This means that the Froude and Reynolds numbers at the inlet channel were Fr_{in}= 0.1 and Re_{in} = 28'000. The circulating discharge was monitored by an electromagnetic flow meter, and the water level was regulated by a flap gate placed at the end of the outlet channel.

3 UVP MEASUREMENTS

A horizontal movable square grid (overall dimensions: 1 m x 1 m) formed by 8 UVP transducers (2 MHz) allows to measure the two horizontal velocity components in 16 points, placed at the intersections between the velocity profiles recorded by each transducer (Figure 2). The distance between each point of measurement is about 24 cm.

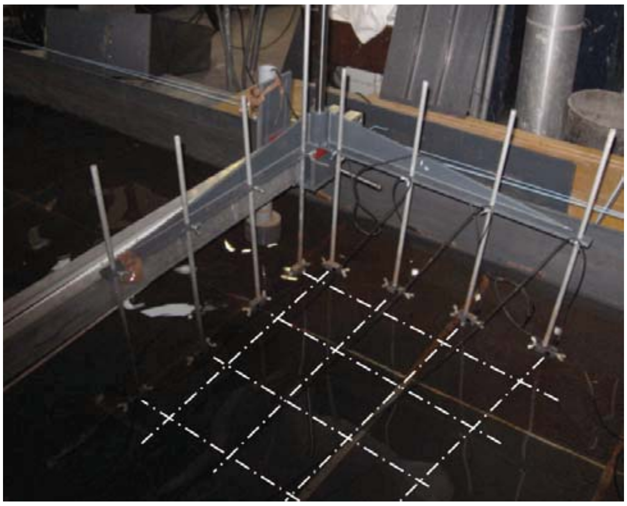

Figure 2: Photos of the movable square grid formed by the 8 UVP transducers. The directions of the measured horizontal velocity profiles are represented by dashed lines.

Since the water depth is much smaller than reservoir horizontal dimensions, the vertical velocity component can be neglected, as typical for shallow free surface flows. UVP measurements of the vertical velocity component were carried out as well, to confirm the assumption of a negligible vertical velocity with respect to the horizontal components.

The transducers were placed at a distance of 8 cm from the bottom that is at 40% of the water depth. In fact, velocities at different height from the bottom were measured in different reservoir positions. It was found that placing the transducer at about one half of the water depth lead to a good approximation of the average horizontal velocity components. The grid was moved by steps, in order to cover the whole reservoir surface. Sixteen positions of the grid were necessary to cover the whole reservoir surface. Therefore, the resulting flow field was not instantaneous. Nevertheless, the flow steady state guarantees steadiness of velocity acquisitions. Acquisition time and the number of recorded profiles were optimised to depict the average flow field developing in the reservoir.

Every transducer can measure velocities up to a distance of 723 mm in the way that maximum recordable velocities are up to 0.189 m/s, which is more than the maximum expected velocity. The relationship linking the maximum distance of measurement P_{max} to the recordable velocity range V_{range} is:

$$V_{range} = \frac{c^2}{4 \cdot f_0 \cdot P_{\max}} \qquad (1)$$

where f_o = ultrasound basic frequency (2 MHz for the adopted transducers) and c = sound velocity (1480 m/s in water).

Equation (1) calculates the amplitude of the velocity measurement window that is 0.3787 m/s. In the present case, since velocities can be both negative and positive, the velocity recordable range is -0.18 ÷ +0.18 m/s.

The measurement window is formed by 232 channels; it means that every profile recorded by the transducer is formed by 232 points of measurement.

The minimum sampling time of 39 msec is assumed for the measurement of every profile. Ten profiles are taken for each transducer, then a pause of 100 msec occours, and the registration of the other 10 profiles of the successive transducer starts.

Table 1: Characteristic parameters used for UVP acquisition.

Maximum measurable depth	723 mm
Velocity range of measurement	-0.189 m/s ÷ + 0.187 m/s
Number of samples: profiles acquired for every transducer during one cycle	10
Number of transducers	8
Number of cycles	20
Minimum sampling time	39 ms
Delay between transducers	100 ms
Delay between cycles	100 ms
SIGNAL	
Transmitting frequency	2 MHz
Number of cycles per pulse	4
Number of repetitions	32
Channel width (spatial resolution)	1.48
MEASUREMENT WINDOW	
Start - End	33 - 721 mm
Number of channels forming every profile	232
Channel distance	2.96

So, every cycle is formed by 10 profiles times 8 transducers resulting in 80 velocity profiles. After the first cycle, a 100 msec delay occours, and another cycle of all the transducer starts: on the whole, 20 cycles are taken.

An average map for every cycle is produced, showing the velocity vectors in the 16 points of intersection of the profiles recorded by the transducers. Then, a final average map is obtained, averaging the 20 maps produced for every cycle. The whole measure lasts about 2 min. Afterwards the grid can be moved to the following position. In the end, placing the vector maps in the reference coordinate system of the reservoir, it is possible to compose all the registered average maps, in the way to depict the whole reservoir flow field.

4 TESTS WITH SEDIMENTS

After carrying out measurements of the velocity flow field developing in clear water conditions (during which only a small amount of suspended particles was added to water, in the way to provide a sufficient echo for UVP measurement) for the different reservoir configurations, a sediment supply was added to the inflowing discharge by a mixing tank. Sediments were fed from a sediment tank into the mixing tank, where they were mixed uniformly with water by a rotating propeller. The resulting mean inflowing concentration was about 2 g/l that corresponds to a solid discharge of 50 kg/h. The sediment supply lasted for 4 hours, for a total sediment inflow of 200 kg. The experiment was stopped after the first 2 hours, to measure the intermediate thickness of sediments deposited on reservoir bottom by a laser (Baumer, OADM13). Then, other 2 hours of sediment supplying were performed, and the final thickness of sediments deposits was measured. The concentration was monitored at the inlet and at the outlet channels by two turbidimeters (Solitax SC, [6]). The values of turbidity measured at the outlet were about 50% of the Inlet concentration, with some differences on reservoir trapping efficiency depending on the geometrical configuration.

The sediments used for the experiments were crashed walnut shells of mean diameter d_{50} = 89 μm, with bulk density of the dry sediments ρ_{dry} = 550 kg/mc and a grain density ρ_s = 1500 kg/mc. Their mean settling velocity is v_{sed} = 1.9 mm/s, according to the Stokes' law applied on d_{50}.

5 RESULTS

The first tested configuration was the symmetric one, having the inlet and outlet channel placed both on the longitudinal axis of the reservoir. This configuration leads to a stable symmetric flow pattern formed by 2 main symmetrical gyres on both sides of the main water jet that links directly the inlet to the outlet channel. It was chosen to start from this initial configuration to analyze the influence of asymmetrical positions of inlet and outlet channels on flow field and sediments deposits.

Two extremes configurations were tested: one (Figure 3 b) has the inlet and the outlet channels placed both near the corners adjacent to the right side of the reservoir; the other one (Figure 3 c) has the two channels placed at opposite reservoir corners. In the end, an intermediate configuration (Figure 3 d) was investigated: the inlet channel was in the middle of the upstream side, while the outflow was placed on one corner of the downstream side.

The main water jet presents, near the entrance of the reservoir, the highest velocity values, about 140 mm/s, as the average velocity expected for the 0.25 m x 0.2 m inlet channel subjected to a discharge of 7 l/s. Downstream, the water jet begins its spreading and mixing process with the water of the reservoir. Velocity begins to decay, the jet width increases, and vortexes develop, originating recirculation zones. The maximum thickness of sediments deposits is placed along the main jet pattern, showing bed forms and reaching a maximum height of about 40 mm. On the contrary, in correspondence of the recirculation zones which are characterized by low velocities, sediments deposits have a smaller thickness (about 10-20 mm) and a more uniform distribution.

A remarkable phenomenon happens for configuration (c): the flow pattern developing during tests with sediments (c2) is different from the one that develops during clear water tests (c1). For clear water tests, the main jet is deflected towards the side of the reservoir nearer to the inlet channel, then the jet follows the right reservoir wall and downstream wall, and it reaches in the end the outlet channel. A big recirculation clockwise zone develops in the centre of the reservoir. On the contrary, during tests with sediments, after 30 minutes of sediment supply the deposits on the bottom create a roughness sufficient to deflect the main jet towards the centre of the reservoir. The main jet follows a direction oriented towards the outlet channel, even if the inlet and the outlet are not directly linked by the main jet. It flows against the downstream wall then it divides itself in two parts, giving raise to 2 big recirculation zones. This flow structure remains then stable for the remaining part of the experiment.

The last configuration (d) is the intermediate one: the main jet reaches directly the exit of the basin and two eddies of different size and shape develop on each side of the main jet.

6 CONCLUSIONS

By the help of UVP measurements it could be observed that in some cases a different flow field can develop in the same reservoir configuration during clear water tests or during tests with sediment supply. This fact shows that not only the velocity flow field influence sediments deposition, but also that the deposits themselves have a strong feedback on the flow field. In fact, they can completely modify the flow patterns, and in particular the direction of the main jet from the inlet to the outlet.

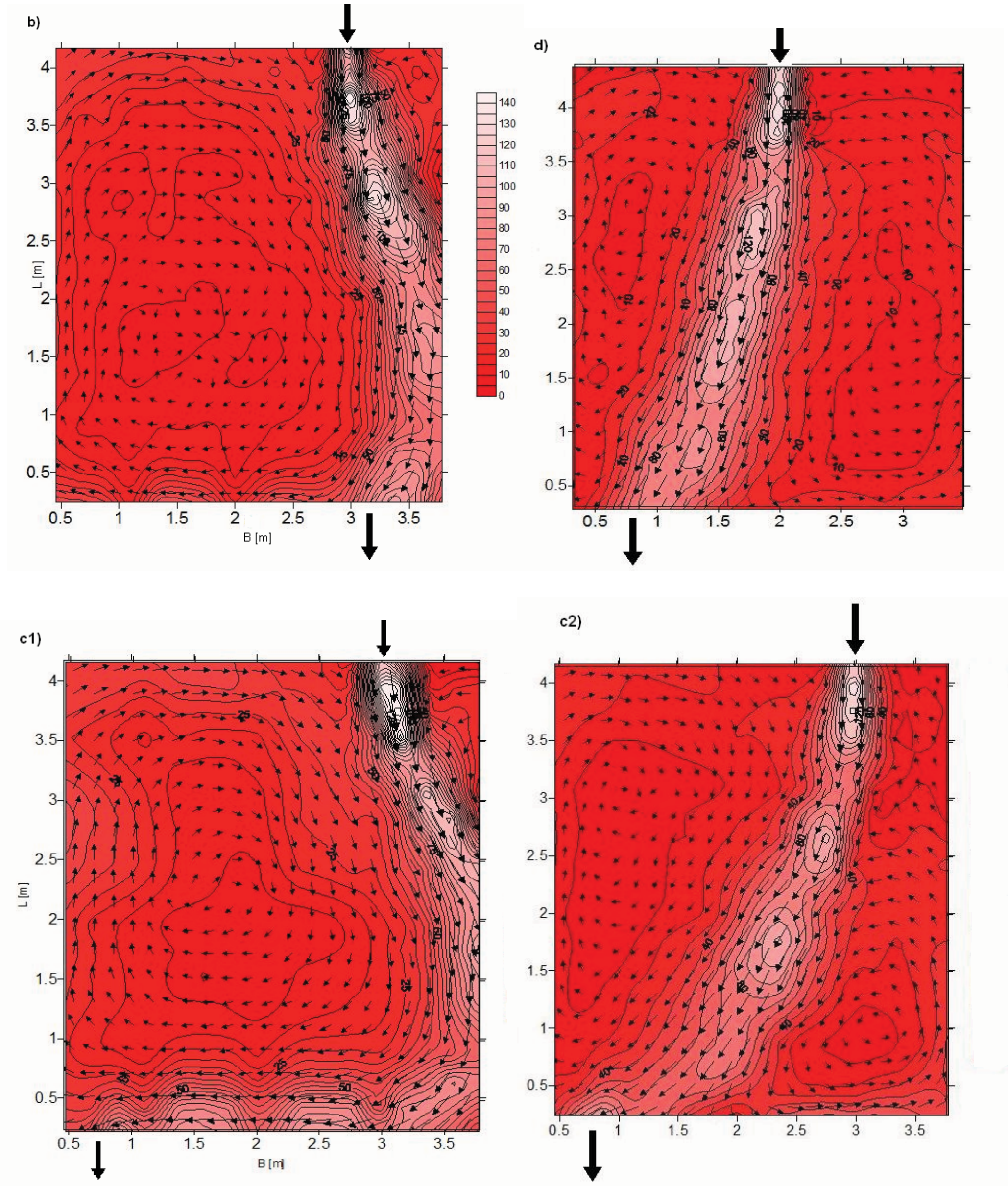

Figure 3: Examples of velocity maps [mm/s] for some of the tested reservoir configurations. b) inlet and outlet channel on the right side – c1) inlet on the right and outlet on the left, test without sediments supplying – c2) inlet on the right and outlet on the left, test with sediments supplying – d) inlet in the centre and outlet on the left. (Q = 7 l/s – h = 0.2 m).

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