DETERMINATION OF VELOCITY PROFILES AND BED MORPHOLOGY USING UVP TRANSDUCERS TO INVESTIGATE THE INFLUENCE OF LATERAL OVERFLOW ON MOBILE BED

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ABSTRACT

Lateral side weirs on channels are widely used in irrigation engineering and flood regulation. They are installed at the wall along the side of the main-channel to spill water over them when the water level in the channel rises above their crest. This lateral loss of water is responsible for the reduction of sediment transport capacity in the main-channel by decreasing the bottom shear stress. This yields to the formation of sediment deposits which raise the bed level locally. The design discharge to be diverted over the side weir is therefore increased and consequently sediment transport capacity is further decreased. This interaction between lateral overflow and sediment transport has to be known in order to avoid undesirable consequences. With the help of an experimental setup the physical processes in the main-channel and on the side weir were analyzed systematically confirming the processes mentioned above. They are strongly transient showing a tendency towards an equilibrium state of the river bed. The presence of mobile bed material forms an important part of these processes. Without paying attention to detail, resulting errors may be in the order of 25 %.

Keywords: Ultrasonic Velocity Profiler (UVP), velocity profile, lateral overflow, side weir, bed morphology, bed-load transport

INTRODUCTION

The content of the present paper results from the multidisciplinary flood protection research project *DIFUSE* (**Di**gues **Fu**sibles et **S**ubmersibl**e**s, Fuse plugs and overflow dams at rivers) involving governmental offices, private companies and four research institutes. The task of the *Laboratory of Hydraulic Constructions* (*LCH*) is to study the effects of a side overflow on the sediment transport in a natural channel.

At the current stage of research, the available published work is limited to only one of these aspects. Lateral overflow, sediment transport and bed morphology are treated as a single problem and nearly no publications relate these phenomena to each other. Due to this lack of knowledge, the particular objectives of the *LCH* contribution are to collect experimental data which can be used to conduct a non-dimensional parameter analysis to predict the hydraulic behaviour of the diverting weir. Combined with a photogrammetrical approach, the purpose is to determine river bed changes and to find empirical relationships. Furthermore, the collected data serves as main-input to generate a 3D numerical model.

EXPERIMENTAL MEASUREMENTS

Channel facility and tested parameters

With the help of a 30 m long and 2.0 m wide flume, the hydraulic and geometric characteristics of the main-channel and the side weir were analyzed systematically to determine the influence of laterally placed side weirs on sediment transport, erosion and deposits in the main-channel. The flume was subdivided longitudinally into two separate channels by a vertical 0.9 m high smooth wall. The first channel, being 1.5 m wide, represents the actual testing facility including the mobile bed and the side weir on the right river bank. The second one, 0.47 m wide, constitutes a lateral channel permitting to evacuate the laterally diverted discharge. A general layout of the experimental setup is shown in Figure 1. The main-channel discharge (117 – 220 l/s) including flood hydrographs, diverted discharge, channel slope (0.1 – 0.4 %), length of the lateral weir crest (3.0 m, 2 x 2.5 m), number of weirs (1 or 2) and sill height (0.09 m, 0.10 m,) were considered as test parameters.

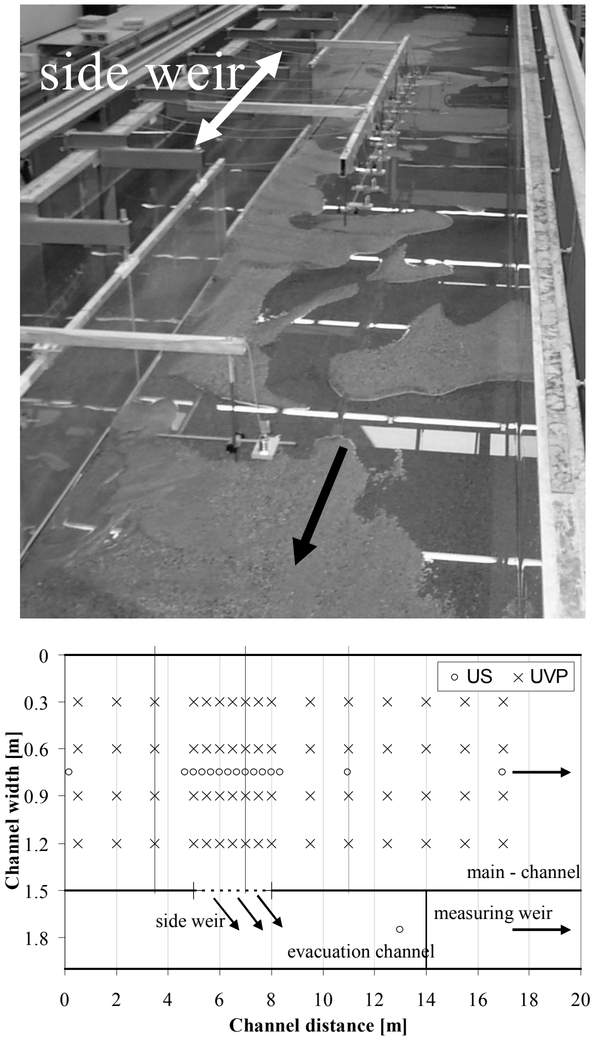

Fig. 1 General view of the test facility with the main channel, the lateral side weir, the mobile bed and evacuation channel (top) and disposition of water level (US) and velocity (UVP) recording (bottom)

Measuring procedure

The channel facility is originally horizontal. The bottom slope is created by adjusting the mobile bed to the requested slope. The mean thickness of the sand layer is 0.24 m. The bed material used in all tests consists of sand having a mean diameter of d_m = 0.75 mm. The sediment quantities to be supplied at the upstream end of the flume have been estimated according to the formula of Smart & Jäggi [1]. Sediment feeding was adjusted during the test in order to maintain a constant water level for a certain discharge thus maintaining uniform flow conditions in the upstream stretch of the flume. The upstream discharge was delivered by the use of three pumps feeding one pipe controlled by an electromagnetic flow meter.

A steady flow rate could therefore be easily set and maintained accurately throughout the duration of each test. The diverted discharge was measured by a standard sharp-crested weir installed in the evacuation channel.

Water depth along the main-channel as well as on the sharp-crested weir in the lateral channel were recorded continuously with a frequency of one measurement per second by the use of an ultrasonic gauge (voltage between 0 and 10V). The voltage was transformed into a distance to a reference level located at the crest of the side weir. The error of the level measurement is less than 1 mm (average ± 0.5 mm). Altogether, 15 ultrasonic gauges were installed longitudinally in the centre line of the channel, one located upstream of the side weir, 12 in the reach of the side weir (every 0.33 m), two downstream of the weir and one upstream of the measuring weir in the evacuation channel (Fig. 1).

Velocities were measured with an Ultrasonic Doppler Velocity Profiler (Metflow SA, Model UVP-XW) allowing to obtain instantaneously a 1D-velocity profile over the whole channel depth [2]. For each 1D-profile, 128 data points in time were recorded with a spatial resolution of 128 points over flow depth. Eight probes, each inclined by 25°, were mounted on a measuring frame fixed on a traversing beam whereof four probes were orientated in the longitudinal channel direction and four perpendicular to the main-channel axis, thus allowing to constitute a 2D velocity field (Fig. 2). The used probes had an emitting frequency of 2 MHz. Velocity profiles were recorded every 30 minutes for 16 cross sections, whereof three were located upstream of the weir, seven in the array of the weir (every 0.5 m) and six in the downstream section of the channel (Fig. 1). The velocity measurements were also used to detect the bed. The surface was obtained from the signal for which the velocity as well as the variance were close to zero [3] [4].

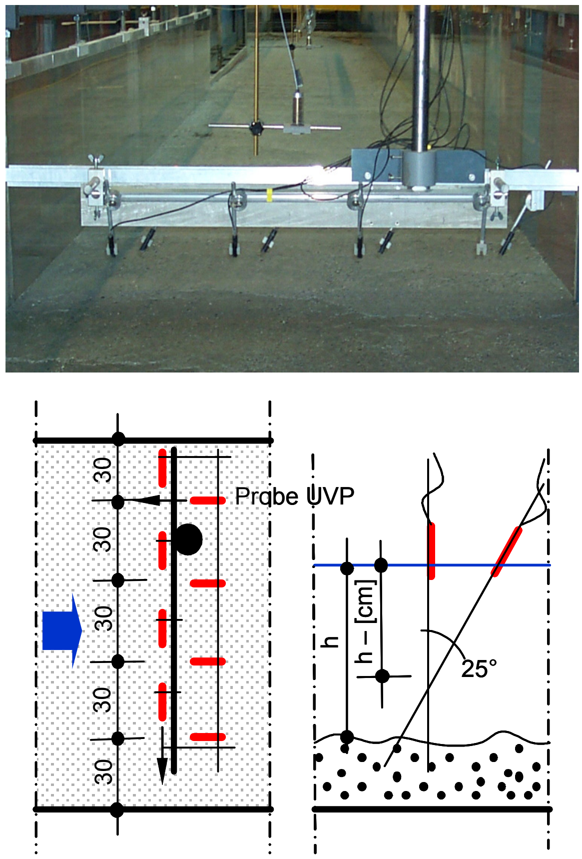

Fig. 2 Disposition and configuration of UVP probes on the measuring frame

As far as the monitoring of the river bed topography is concerned, a photogrammetrical approach has been applied serving as a three-dimensional surface measurement tool. For the present study five photographs with an overlap of 60 % have been taken to cover the whole channel. This has been done for the initial flat bed situation and after each experiment for the final bed situation after controlled drainage of the channel. 18 photocontrol points distributed along the channel facility and in the laboratory were used for the orientation and triangulation process. For the creation of the DTM a grid resolution of 2,5 x 2,5 cm has been chosen.

RESULTS AND DISCUSSION

Water level and diverted discharge

Due to the passage of dunes, water level measurements reveal strongly transient processes owing an oscillatory character. At the beginning of each experiment the water level in the main channel as well as the one over the measuring weir in the evacuation channel increases. With elapsing experiment time the level reaches a maximum before tending towards an almost constant value. This behaviour is more or less distinctive depending on the initial discharge. As far as the diverted discharge (Q_D) is concerned, the water level in the evacuation channel has been transformed into a discharge using the equation for sharp-crested weirs. Compared to the initial discharge introduced upstream (Q_1), Q_D amounts on average to 17 % of the total discharge introduced (Fig. 3, top).

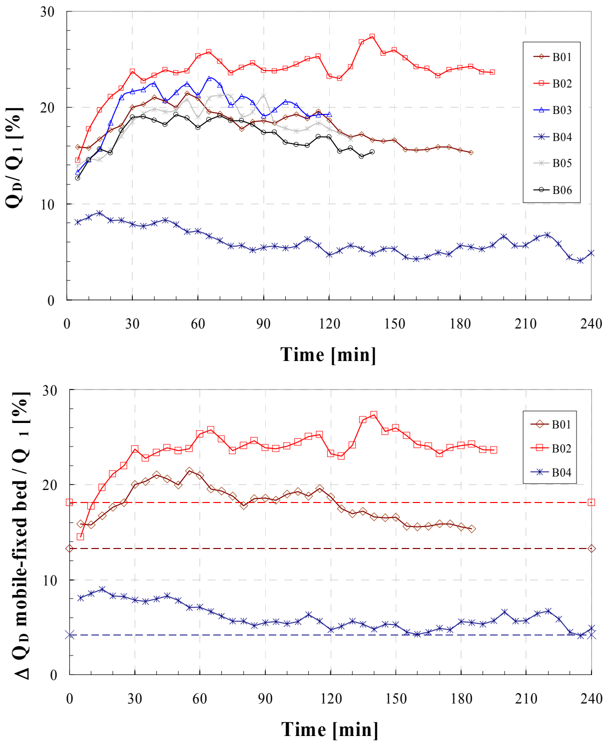

Fig. 3. Temporal evolution of diverted discharge (Q_D) in percentage of total discharge (Q_1) (top) and comparison of Q_D for mobile and fixed bed conditions with Q_1 (bottom)

The lowest value of 4 % is obtained for the smallest discharge, the largest one of 28 % for the highest discharge. Compared to fixed bed conditions (Fig. 3, bottom) it can be noticed that the ratio Q_D/Q_1 averages to be 25 % higher with a mobile bed thus corresponding to [5].

Velocities

The velocity recordings revealed an interesting effect of the Doppler measurement device which has been described earlier [3]. If the measured velocity was higher than the maximum velocity, the UVP shifts the measured value by minus 2 times the velocity range to the negative domain of the measurement and vice versa. If the sign of the velocity is known, the recorded velocity can be corrected by shifting the negative (positive) values again to the positive (negative) domain [4]. Qualitative and corrected velocity profiles in channel axis and perpendicular to the weir for three cross sections situated upstream, in the weir alignment and downstream are plotted in Figure 4. For each cross section, a profile at the beginning and at the end of the test has been measured at 0.9 m channel width (Fig. 1).

The profiles in flow direction (Fig. 4, top) at the beginning of the experiment are almost homogenous to become significantly disturbed in the weir alignment as well as in the downstream channel section. The distance to the free water surface is nearly equal for all profiles indicating an almost similar water depth. From this, a rather regular and undisturbed bed morphology can be concluded. At the end of the test, a typical velocity distribution is encountered for the upstream part whereas further downstream distortions come across. The distance to the free water surface decreases. Assuming a horizontal water surface level, the bed level has therefore increased.

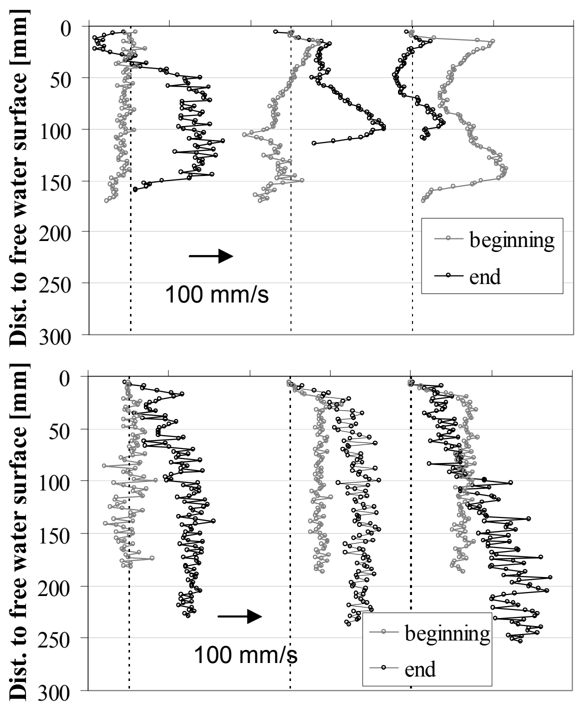

Fig. 4. Velocity measurements parallel to channel axis (top) and perpendicular (bottom) upstream, in the weir alignment and downstream at the beginning and at the end of test run B02. Dashed line: v = 0 mm/s

The velocity profiles perpendicular to the weir (Fig. 4, bottom) are nearly constant over flow depth for the beginning of the test run. With elapsing time the velocity component towards the weir increases.

The velocity measurements have also been successfully used for the detection of the bed surface (see next paragraph). Therefore the development of the bed over time can be determined, which is not possible with the photogrammetrical treatment since only the final bed situation can be measured. The information about the ground is less dense because only eight points for the eight probes are obtained instead of 1.5 m/0.025 m = 60 points from the photogrammetry. Nevertheless, it helps to get an idea about the development of the bed over time.

River bed morphology

After introducing the flow to the prepared initial flat bed by a small discharge, a rapid change of bed roughness due to the formation of dunes appears. Upstream of the side weir the dunes are of quite uniform character whereas in the reach of the weir and downstream the regular formation is clearly disturbed.

Based on the photogrammetrical analysis the DTM for the final bed situation has been determined. Typical cross-section profiles for different locations along the main channel are shown in Figure 5. The formation of sediment deposits in particular in the reach of the side weir are clearly apparent leading to a reduction of the cross section of about 33 %. A volumetric balance for a 7.0 m stretch reveals a deposited volume of 0.044 m^3 or 116 kg. Due to the reduction, the flow velocity opposite to the weir is increased resulting in an oscillatory erosion process before attenuating. In Figure 1 these observations are pointed up in a qualitative way. Outgoing from the weir side, an erosion gutter, at the end of the test still filled with water, is running to the right and again to the left. Sedimentation reaches on the right bank are followed by eroded reaches on the left bank.

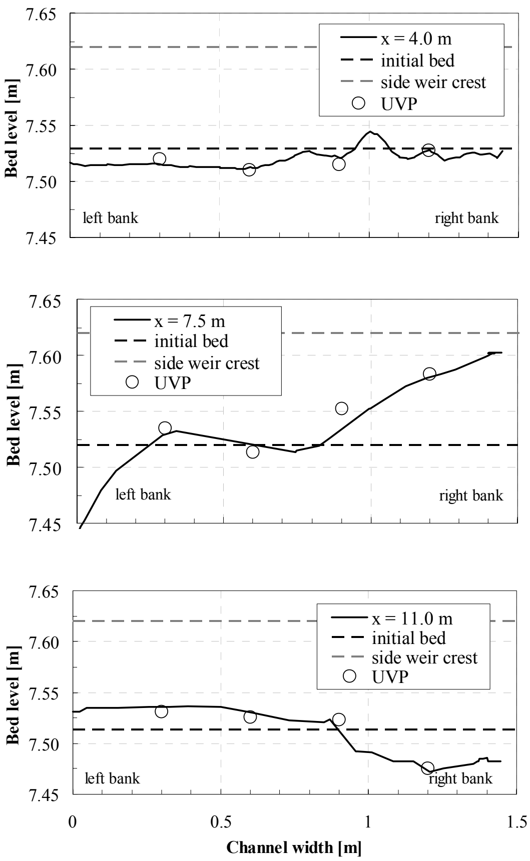

Fig. 5. Cross sectional profiles for the final state of the river bed upstream, in the weir alignment and downstream (from top to bottom)

The detection of the ground using UVP measurements are in fairly good agreement with those obtained from photogrammetry thus permitting an analysis of the temporal evolution of the bed morphology.

CONCLUSION AND PERSPECTIVE

An essential prerequisite in the field of flood protection is the capability to design and to predict accurately the behaviour of flood control devices such as lateral side weirs. In many cases the behaviour of mobile bed material will form an important part of this process. It has already been demonstrated that without paying attention to detail, errors in calculating can be of the order of 30 % [5].

The analysis of experimental test series confirms the formation of local deposits of sediments in the reach and downstream of lateral side weirs, particularly on the weir side of the channel. The flow is attracted by the lateral side weir leading to progressive modification of the bed morphology and an elevation of the bed near the weir alignment. On the one hand the deposits increase the flow velocity opposite to the weir resulting in additional stress to the bank since the cross section is reduced up to 30 %. On the other hand the bed elevation is combined with an elevation of the water level leading to an increased diverted discharge over the side weir. Compared to fixed bed conditions the ratio diverted discharge/ main channel discharge is about 25 % higher. Due to the migration of dunes this process is strongly transient since at the beginning of the experiment the diverted discharge/main-channel discharge ratio is low, then rapidly increases to a maximum before reaching almost a constant value. A tendency towards an equilibrium state of the river bed is observed which is also indicated by a strongly wavy water surface in the reach of the side weir at the beginning of each test which becomes smoother with elapsing experiment time.

Based on the examination of the first test series, the remaining experiments will be analysed according to the same procedure to finally perform a non-dimensional parameter analysis and to develop empirical relationships for the hydraulic and sedimentary behaviour. The collected data will also serve to calibrate a 3D numerical model in order to analyze the observed effects in detail and to widen the application range.

A better understanding of the interaction between sediment transport and lateral overflow will allow to develop and to provide appropriate design criteria for engineers involved in the design of fuse plugs on rivers in the framework of flood protection projects.

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