Table 1: Measurement results for flow point which is 25.9 mm away from pipe wall

NRe	V_{mean}(mm/s)	Area under spectrum	Standard deviation of P.U.S. spectrum	Maximum amplitude in P.U.S spectrum	Normalized Maximum amplitude by area under P.U.S. spectrum
1022	12.70	1.2860	0.0046	102.60	79.78
1227	14.20	1.1646	0.0051	95.98	82.41
1449	17.90	1.1401	0.0045	94.84	83.18
1508	23.30	1.8503	0.0071	118.80	64.20
1878	27.10	1.7660	0.0073	109.00	61.72
2022	31.20	1.7320	0.0061	119.60	69.05
2438	33.70	1.7306	0.0057	110.50	63.85
2487	36.40	1.5276	0.0065	95.97	62.82
4331	44.60	2.6314	0.0137	105.00	39.90
7832	75.40	3.0949	0.0168	88.74	28.67
10518	98.05	4.2960	0.0224	94.97	22.10
12694	118.90	4.7100	0.0254	93.88	19.93
14159	133.47	5.4701	0.0281	93.60	17.11
17530	178.50	7.2060	0.0381	94.68	13.14
20452	200.60	11.3400	0.0463	114.30	10.08
24542	244.99	10.3900	0.0495	98.92	9.52

Flow velocity measurements using Ultrasound Doppler Velocity Method - 10 years experience in hydraulic modeling -

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The Ultrasound Doppler Velocity Profile method (UVP method) has been developed for fluid mechanical measurements in physics and engineering. The principle of the method is straightforward; Ultrasound echography and Doppler effect. This method was originally applied in medical engineering to measure blood flow. The developers of the instrument subsequently extended this method to non-medical flow measurements and implemented specific application systems. The method itself was found to be quite useful to flow measurements in general. Through years of use it has gradually become accepted as a tool to study the behavior of fluid flow. The present paper will not focus on the measurement method itself, but some applications at the Laboratory of Hydraulic Constructions (LCH) of the Ecole Polytechnique Fédérale de Lausanne (EPFL) will be reviewed. After a short introduction to the missions and equipment of LCH, an insight look at some results of past and ongoing research projects will be presented. The subjects cover a very large range of applications and configurations in hydraulic engineering. The Ultrasound Doppler method for velocity profile measurement has now become established at the LCH as a user-friendly research and monitoring tool.

Keywords: Ultrasound Doppler Velocity Profile, UVP, physical modeling, hydraulic engineering, flow measurement

1 INTRODUCTION

The first Ultrasound Doppler Velocity (UVP) Profile measuring instrument has been purchased by the Laboratory of Hydraulic Constructions (LCH) of the Ecole Polytechnique Fédérale de Lausanne (EPFL) in 1995. Its first application was to monitor the unsteady flow field of turbidity currents reproduced in a laboratory flume.

The LCH activities comprise education, research and services in the fields of hydraulic structures and schemes. Aspects of hydraulic structures related to flood control, hydropower plants, water supply, dams, etc. are studied. These investigations are mainly carried out using physical scale models and numerical simulations or a combination of both (hybrid modeling).

Research carried out at the LCH concentrates on the interactions of hydraulic structures and schemes with their environment, in particular with water, sediments, air and underground. The ongoing projects at the LCH focus on the following themes:

- Natural hazard, extreme floods, debris flow, sediment transport and erosion in catchment areas and rivers
- Dynamic water solicitation due to plunging jets, pressure propagation in rock fissures, scouring in fissured media
- Reservoir management, influence of reservoir geometry on sedimentation
- Development strategy for new multi-purpose hydropower schemes, reduction of hydropeaking effects by river training works
- Hydro-informatics, numerical simulation of water flow in complex hydraulic systems
- Fluvial hydraulics, flow in river bends, overflow dams and fuse plugs at river banks, bioengineering in river training works
- Shore erosion protection measures, oil spill retention systems

Teaching at the LCH includes university level courses at graduate and master levels, taking into account environmental and socio-economic aspects. Master of advanced studies (MAS) in water resources management and engineering, with special focus on hydraulic schemes are also offered.

Services such as consulting and commissioned studies are offered to the public and private sectors in the field of applied hydraulics, transferring LCH know-how acquired through research projects.

The UVP instrument has been used in research, education and services as well. In the presented paper, the measurement method itself will not be described, but some representative applications at the LCH will be reviewed.

2 FLOW VELOCITY MEASUREMENTS IN RESEARCH

All major research activities at the LCH comprise physical modeling. Since 1995, out of 16 PhD theses accomplished or ongoing at the LCH, 8 used or are using ultrasound Doppler velocimetry in their experimental research. The following illustrated list shows all PhD studies where flow measurement using ultrasound techniques is concerned.

1995-1998: G. De Cesare - 1 and 2D Turbidity current monitoring in a physical model flume [1]. The overall objective of the study is to evaluate reservoir sedimentation due to turbidity currents, Fig 1.

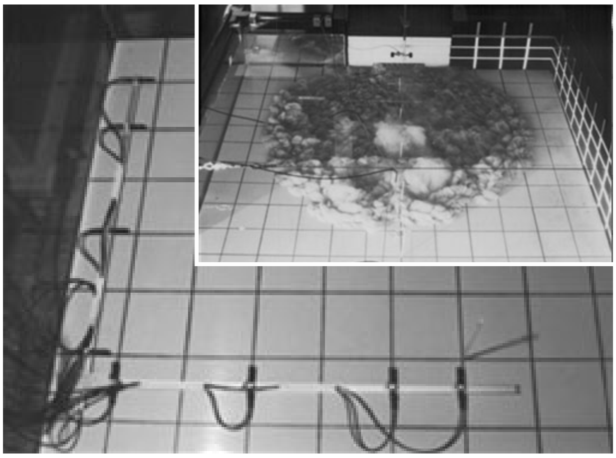

Figure 1: Layout of UVP probes on a fixed 4x4 frame to asses the 2D velocity distribution inside a turbidity current. Small picture: Spreading current with frontal arrangement of UVP probes to monitor the advancing front

1999-2003: D. Hersberger - 3D flow monitoring to assess wall roughness effects on flow and scouring in curved channels with gravel bed [2]. The wall roughness is created by vertical ripples on the outer side of the river bend, Fig. 2.

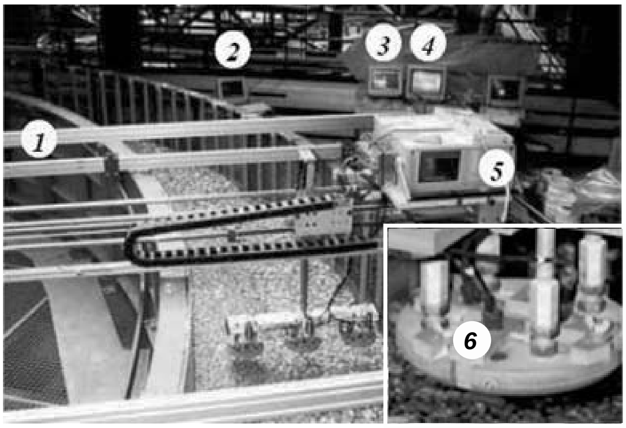

Figure 2: Arrangement and configuration of 9 UVP probes on a 3D traversing system to measure flow circulation in a 90° river bend, 1) Measurement frame, 2) Discharge controller, 3) Frame controller, 4) Level acquisition 5) Velocity acquisition, 6) UVP probes and support

2000-2003: Ch. Oehy - 2D flow monitoring to determine the effects of obstacles and jets on sedimentation due to turbidity currents in a flume [3]. In its final application, this research work gives valuable information on how to design obstacles in reservoir to reduce sedimentation induced by turbidity currents in the lowest part of the basin, Fig. 3.

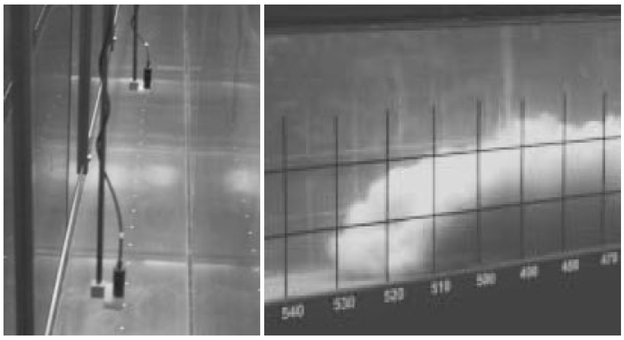

Figure 3: Layout of UVP probes (left) to asses velocity profiles inside a turbidity current (right) in a flume

2000-2006: B. Rosier - 2D flow monitoring to investigate the influence of lateral overflow on mobile bed [4]. As a result, the design principles for lateral overflow spillways have to be reconsidered taking into account the evolution of the mobile bed in rivers, Fig. 4.

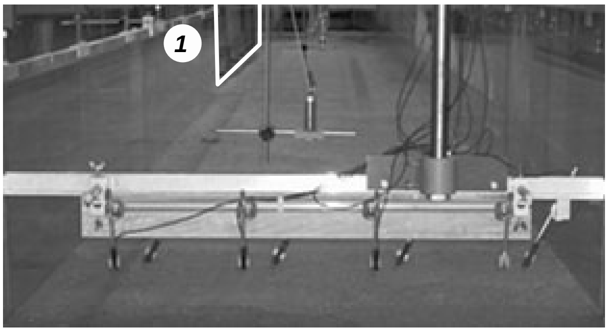

Figure 4: Layout and configuration of the 8 UVP probes on a measuring frame to monitor the flow in a flume with a side wear 1)

2003-2006: T. Meile - 1D velocity profile measurement of rapid wave propagation in a flume. This project is part of the research work related to hydropeaking effects in natural rivers.

2004-2007: A. Amini - 2D UVP measurements of the flow around a floating barrier for confinement and recuperation of oil slicks.

2005-2007: S. Kantoush - 3D circulation measurement in a shallow reservoir to study its influence on sedimentation.

The tree above cited ongoing research project and their relation with UVP are object of three papers in the 5th ISUD.

2006-2008: A. Duarte - 3D flow measurement to investigate main flow, secondary flow and turbulence in open-channel bends and their interaction with outer-bank geometry.

PhD research studies always require the best and most accurate instrumentation available. UVP is such an efficient and valuable monitoring tool that convinces researchers in all major scientific fields in hydraulic engineering.

3 FLOW VELOCITY MEASUREMENTS IN COMMISSIONED EXPERIMENTAL STUDIES

Consulting and commissioned studies are offered to the public and private sectors in the field of applied hydraulics, dealing with river engineering, flood protection, hydropower exploitation and reservoir operation.

Among the first ones in 1996 was the study of the flow circulation in the Essert compensation basin, part of the hydropower scheme of Emosson in the Canton Valais. The model was built in a 1/30 geometrical scale in order to study the sedimentation processes pattern as a function of inflow and outflow conditions, Fig. 5.

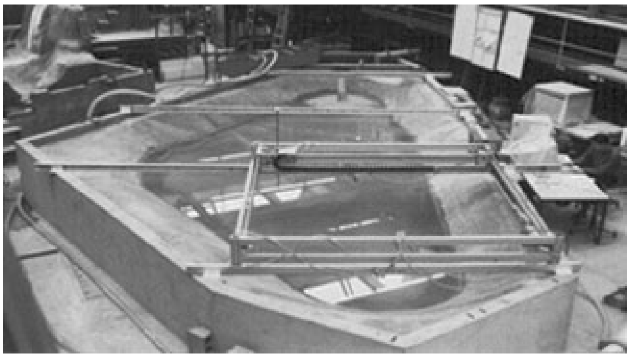

Figure 5: The physical scale model of the Essert compensation basin, UVP probes fixed on a 3D traversing frame

In 1997 the behavior of muddy debris flow through the Pissot discharge control structure located on the Highway A9 south of Montreux was investigated [5].

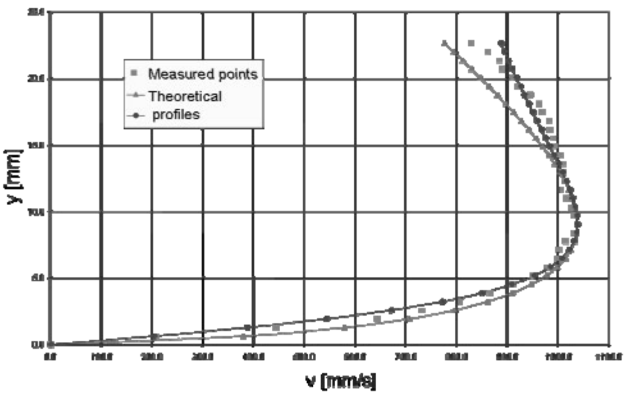

Figure 6: Results of the calibration of the theoretical velocity profiles based on the measured profile for mud flow

The required hydraulic capacity of the canal has been tested with fluids of different volumetric concentrations and therefore different rheological behaviors. UVP measurements of the mud flow allowed to asses the flow velocity distribution inside the fluid, Fig. 6. The transducers were fixed on the flume bottom looking upwards.

In 1998, a physical model was built to asses the efficiency of measures to reduce the silting up of a waste loading station at the junction of the Rhone and Arve Rivers in Geneva, Fig. 7. Flow direction and velocities inside the lock could be measured to compare the various alternatives investigated to reduce sediment deposits at this place. The UVP transducers were fixed outside the PVC side walls of the model.

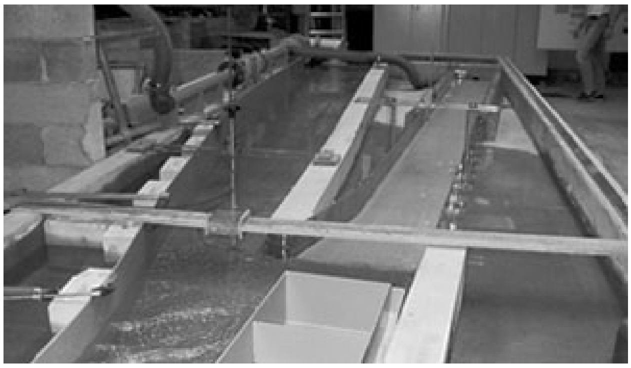

Figure 7: Physical model of the waste loading station facility at the junction of the Rhone and Arve Rivers in Geneva

The same year, in relation with the rehabilitation of the Maigrauge hydropower plant in Fribourg, built in 1870, the approach flow condition upstream of the new water intake have been evaluated using UVP. The physical model was built at a 1/50 scale.

In 2004, as part of the project of the third correction of the Rhone River in Canton Valais, the effect of a gravel mining pit situated in the riverbed close to Rarogne was studied [6], Fig. 8.

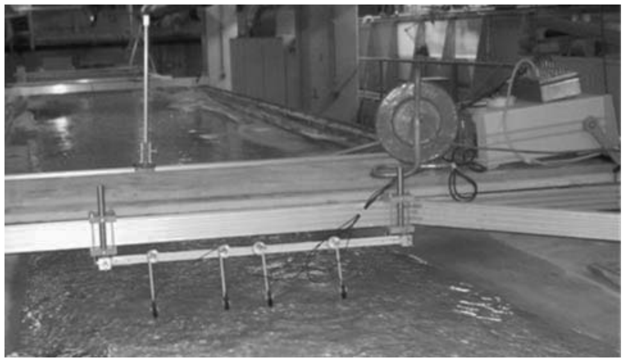

Figure 8: UVP transducers mounted on the measurement platform over the gravel pit in the physical model

A 1/45 scale physical model with mobile bed was constructed and a series of experimental tests were conducted in order to investigate the pit migration. Velocity profiles were measured in different locations using UVP probes. The time evolution of the bed geometry and development of the mining pit could be instantly determined during the test by analyzing the US echo and velocity profiles.

The use of UVP in commissioned studies has become a general rule and is offered nowadays as a standard monitoring tool for flow velocity.

4 FLOW VELOCITY MEASUREMENTS IN EDUCATION AND TEACHING

The LCH offers teaching at Bachelor, Master and Master of Advances Studies (MAS) level. Access to the laboratory facilities for student work is normally granted only for at least Master level within the frame of a diploma thesis. Physical model test for students are in most cases in close relation with a commissioned study, thus allowing the LCH to have an installation ready for students. The first time UVP have been used by students was in 1996 in the Essert compensation basin model (see previous paragraph).

Later in 1998, Lavelli [7] assessed the surface roughness by analyzing the velocity profiles of the flow close to the bottom. Measurements were performed in a 0.30 m wide and 8 m long laboratory flume with UVP. The aim of this study was to determine the equivalent sand roughness k_s for several bottom surfaces such as smooth concrete, negative roughness plates and garden flagstones.

Use of UVP by students has been very convincing and will be offered for existing projects. Since 1998 many students could familiarize with UVP techniques through semester projects related to ongoing research and commissioned projects.

5 CONCLUSIONS

An Ultrasound Doppler Velocity Profiler has been purchased by the Laboratory of Hydraulic Constructions in 1995 to monitor the time depended flow field of turbidity currents reproduced in a laboratory flume. Already during this earliest study, research engineers of the LCH became aware of the great potential of this monitoring technique, finally available in a user-friendly, portable and reliable measuring device. This method is now integral part of the standard techniques normally used in a hydraulic laboratory such as micro-propellers, Pitot tubes, hot wire and laser Doppler anemometers (not available at the LCH) and several types of visual flow tracking methods. Each one has its advantages and disadvantages and limited applicability.

The working principle of the UVP method is straightforward using pulsed ultrasonic Doppler effect together with the echography relationship. An ultrasound pulse is emitted from a transducer into the liquid, and in the case of the UVP instrument the same transducer receives the echoes. Its great advantage resides in the facts that:

1. It obtains a spatio-temporal flow information
2. It is applicable to opaque liquids
3. It is non intrusive
4. It is a line measurement
5. Flow mapping is practicable with multiple transducers

Through UVP technique, each of these advantages is now being exploited in the presented past or ongoing studies. Spatio-temporal flow information is essential in hydraulic engineering studies, where rapidly varying, unstationary phenomena can occur.

Despite the fact that numerous and important improvements have been realized with the original measurement device, further developments are desired, particularly in the following perspectives:

- Detection of moving interfaces (liquid-liquid, solid-liquid, liquid-air)
- 2D and 3D measurements in a stationary flow field with one fixed and one mobile transducer to increase number of intersection points
- Increase of instrument velocity range and distance

Even if most of the engineering studies are undertaken in stationary flowing environments, this non-invasive measuring technique allows monitoring from outside of the control domain, thus not disturbing the flow field.

As shown, the use of UVP covers a very large range of applications and configurations in hydraulic engineering. This measurement method has become established at the LCH as a user-friendly, cost and time effective research and monitoring tool. The rapid availability of flow information is a non negligible advantage of the hydraulic laboratory.

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