APPLICATION OF UVP TRANSDUCERS TO MEASURE BED GEOMETRY AND VELOCITY PROFILES IN A HYDRAULIC SCALE MODEL WITH GRAVEL PIT

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ABSTRACT

As part of the project of the third correction of the Rhone River in Canton of Valais in Switzerland, the effect of gravel extraction from the riverbed in the Rarogne Region was studied. A 1:45 scale physical model with mobile bed was constructed and a series of experimental tests were conducted in order to investigate downstream erosion and changes in sediment transport due to the dredging pit. Three combinations of pit and contraction due to dredging were studied for three flood discharges. The velocity profile was measured in different locations, using UVP (Ultrasonic Velocity Profiler) probes. Having velocity profiles, evolution of the bed geometry and development of the mining pit can be instantly determined during the test. The main difficulty of the analysis was interpretation of the velocity profile in order to detect bed position. Installing four probes along the width of the model, lateral effect of contraction and mining pit on flow velocity was analyzed. Finally, based on results of the tests, recommendations are given for the mining operator, taking into account the local conditions and downstream structures.

INTRODUCTION

Disruption of sediment transport in rivers caused by sand and gravel pits can change bed geometry and endanger the stability of the banks and downstream structures, e.g. bridges. Sediment transport is affected by sudden change in the river section geometry and consequently erosion is anticipated in the downstream of the pit. Therefore, geomorphic and also environmental effects of material extraction are one of the main concerns in river training projects [1].

The 3rd correction of the Rhone River is a project at national scale which deals with all kind of hydraulic activities and structures in the Swiss part of the river. Sand and gravel extraction is carried out in few locations along the river among them in the Rarogne Region.

In the study the evolution of bed geometry due to a mine pit is investigated. A 1:45 scale physical model with mobile bed was constructed and a series of experimental tests were conducted in order to investigate downstream erosion and changing in sediment transport due to the dredging pit model The main goal of this study is to determine the depth and extend of the erosion in the affected zone in order to establish criteria for the mine operator.

Although research was carried out in the past based on laboratory tests and numerical modeling [2], [3] and [4], due to complexity of this phenomenon, scale hydraulic modeling is necessary for each project in order to obtain accurate results. Lee and Song [2] proposed formulas, derived from the experimental results, for different parameters and tried to find an empirical solution to this problem. This set of formulas has been obtained for a rectangular mining pit composed of uniform sediments over the whole river width and for a limited extend of Froude numbers (0.40-0.47).

Its application is limited to cases presenting no lateral contraction and only within the range of the original study.

Referring to these investigations, two different stages can be distinguished in the mining pit migration process, the convection and the diffusion phase (Figure 1). The transition occurs when the lowest point of the pit coincides with the downstream extremity of the pit.

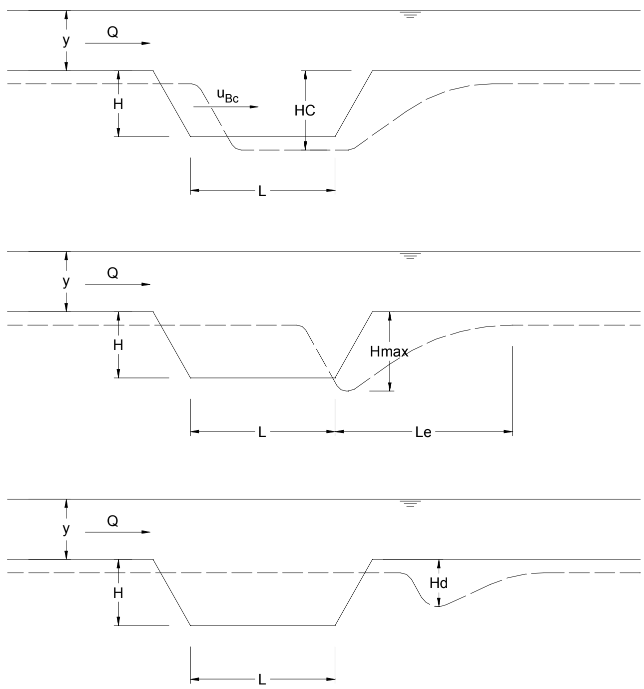

Figure 1: Migration of a rectangular mining pit composed of uniform sediments according to [2]

The Ultrasound Doppler Velocity Profile method (UVP method) has been chosen in the presented model study in order to measure the hydraulic flow characteristics and the bed profile during the transient phenomena. The principle of the method is straightforward; echography and Doppler effect. Originally developed in medical engineering to measure blood flow, its applications nowadays extend to non-medical flow measurements in general fluid mechanics. Due to the inherent constraints of classical anemometry, there has been a clear need to develop and dispose a measurement technique by which one can obtain velocity fields in space and time valuable for the hydraulic engineer. The Method has been applied since 1995 at the Laboratory of Hydraulic Constructions (LCH) to monitor initially the time-depended flow field of turbidity currents, velocity profile measurements for surface roughness determination, modeling of muddy debris-flows and roughness effects in sediment transporting mountain rivers.

PHYSICAL MODEL

The simulated river reach extends to some 800 m (Figure 2) which was modeled at a scale of 1/45 giving the length and width of the model as 16 m to 2.4 m, respectively.

In order to find out the impact of the dredging pit during different flood events, a series of tests were carried out for three discharges listed in Table 1.

Table 1. Three discharges adopted in this study

Return period (yr)	10	50	100
Discharge in prototype (m^3/s)	580	740	820
Discharge in model (l/s)	42.7	54.5	60.4

Since during the mining operation, material deposits causing contraction have also been observed for the mentioned discharges, the three following configurations of dredging pit geometry were tested:

- Big dredging pit, 2 m long, 10 cm deep
- Big dredging pit with contraction, 2 m long, 10 cm deep
- Small dredging pit, 1 m long, 10 cm deep

The contraction is maximum, half of the width, in the beginning of the pit and reaches to zero at the end of the pit. The geometry of the pit was chosen based on observations and measurements performed in different periods of the mine operation in the last 14 years. The hydraulic model constructed for this study is schematically shown in Figure 3.

Figure 2: Limits of the hydraulic model and available cross sections of Rhone River used in this study

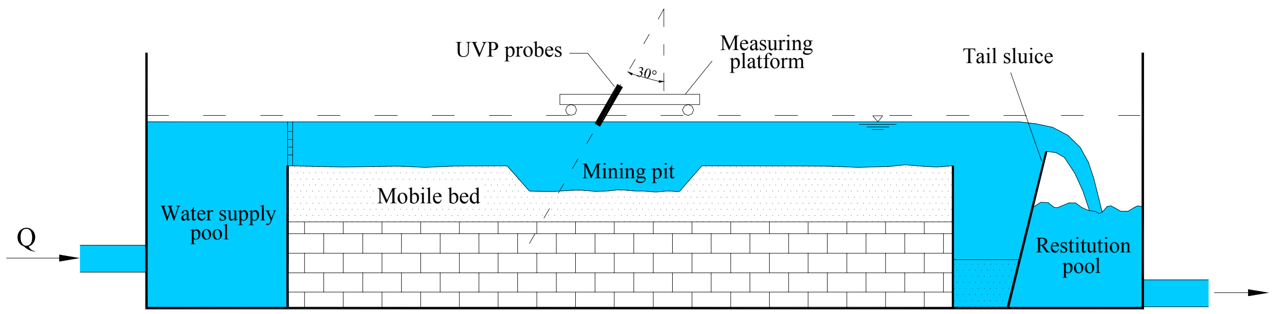

Figure 3: Schematic presentation of the hydraulic model

In order to meet the similarity laws in case of mobile bed modeling, grain diameter used as bed load should be chosen considering the riverbed roughness and type of the bed form. Total roughness must be calculated taking into account roughness by size of the grains and the bed form. Based on the empirical formulas and charts determining the bed form [5], in case of the Rhone River the bed form consists of dunes. Considering total roughness, uniform graded fine sand of 0.2

mm diameter was adopted as bed load. Using very fine sand, saturation of the model become very delicate and local erosion may occur.

Sediment feeding was evenly done on the upstream limit of the model during the tests. The sediment discharge has been calculated for each case based on empirical relations of Smart & Jaggi and Schoklitsch (from [6]). Average values of the above mentioned methods were applied as sediment discharge, Table 2.

Table 2. Sediment feeding discharge

Water discharge (l/s)	Solid discharge (l/s.m)
42.7	0.0060
54.5	0.0075
60.4	0.0100

INSTRUMENTATION

Four UVP (Ultrasonic Velocity Profiler) transducers were mounted on a mobile measurement platform moving along the model, Figure 4.

2 MHz transducers were adopted for the test taking into account the three following parameters:

- Measurement distance range
- Maximum estimated velocity range
- Required accuracy in terms of width of the measurement channel and velocity resolution

Table 3. UVP transducer configuration used in this study

Start point	Channel distance	End point	Maximum depth	Maximum velocity	Velocity resolution	Frequency
(mm)	(mm)	(mm)	(mm)	(mm/s)	(mm/s)	(Hz)
9.4	2.22	293.6	338	809.6	6.3	2188

Velocity profile measurement was conducted every 25 cm close to the pit and every 50 cm in the other parts.

In each measurement station, 100 profiles were measured by each of the four probes, having one second delay to activate the next probes. One full set of measurement over the model was performed at an interval of half an hour.

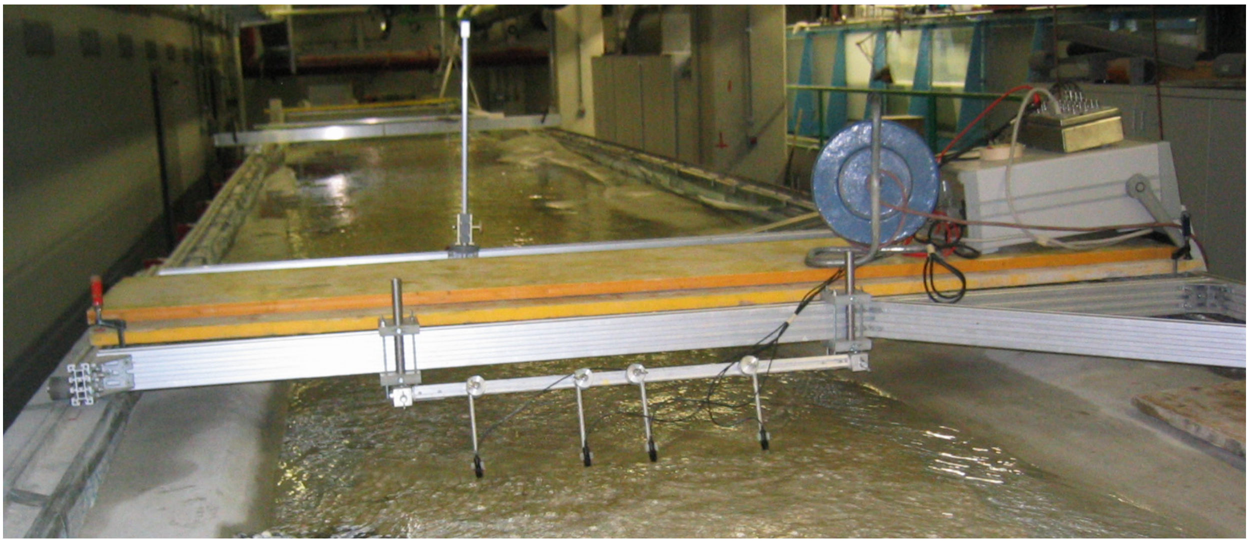

Figure 4: UVP transducers mounted on the measurement platform supported itself by rails

Having velocity profile measured in different distances from the upstream limit of the model, geometry of the bed was determined by detecting the bed position. Velocity profiles can be analyzed using MFX-XW software [8]. The methodology of velocity profile analysis is described as follows:

- Zero velocity
- Zero standard deviation

→ Obvious bed position

- Zero velocity
- Non-zero standard deviation

or

- Non-zero velocity

→ Manual bed detection

In the first case bed position can be easily detected, whereas in the second case more visual attention and work is required in order to accurately find the bed elevation using UVP.

Considerations regarding the application of UVP in mobile bed studies

- Correction of the velocity values due to inclination of the probes with respect to the vertical should be taken into account if real velocity values are required (can be automatically done by MFX-XW software [8]).
- For measuring velocity in a certain position, a number of profiles has to be measured in order to obtain a realistic average profile representing the actual average velocity profile (in this study 100 measurements each time to cover turbulent fluctuations in the steady state flow field).

- Accuracy of the measurement is limited to the width of the measurement channel.
- Sound reflection in the fixed part of the bed (in this case concrete foundation of the model) should be detected and removed while analyzing the water velocity profile.
- Upper part of the velocity profile should also be omitted as it is affected by the turbulence on the surface caused by water flow around the probe end.
- Since the probe is inclined with respect to the vertical, bed elevation detection can be influenced by bed form, e.g. dunes, ripples, etc. This has two aspects: Firstly, the average bed elevation can be wrongly determined by the height of the local dune, secondly if the dunes are relatively big compared to the water depth, bed level reference points are in different positions for aligned probes in the cross section.
- If bed geometry or flow field changes rapidly, it is recommended to install probes at fix positions so that the time needed to place the probes at the right position does not affect the accuracy of the measurements of a transitional phenomenon.

Advantages of UVP transducers:

- Online measuring of velocity profile
- Online measuring of bed elevation without stopping the test, especially in case of transient phenomena.
- Turbulence measurement, limited to acquisition frequency
- 3-D flow field analysis

AUTO BED DETECTION USING UVP

Based on the criteria mentioned above, auto detection of the bed was investigated and the results are presented in Table 4.

Table 4. Results of average velocity profile analysis

Q (l/s)	Case 1		Case 2		Case 3		Case 4	
	No.	%	No.	%	No.	%	No.	%
42.7	39	98	0	0	1	2.5	0	0
54.5	34	85	0	0	6	15	0	0
60.4	16	40	7	17.5	14	35	3	7.5

Case 1: Auto detection of the bed is possible
Case 2: Non-zero velocity
Case 3: Non-zero standard deviation
Case 4: Difficult to detect the exact position of the bed

As it can be seen the possibility of the bed auto detection decreases as the discharge increases. With higher discharges, solid discharge also increases, causing higher sediment transport rate and more indistinct bed position. Therefore, due to the bed load transitional zone (moving bed), a precise bed level almost does not exist any more. By reducing the velocity resolution, the auto bed detection can be more reliable, as in most of the velocity profiles categorized as case 2, minimum velocity is equal to the velocity resolution. It should be said that having less material transport rate inside the dredging pit, bed position could be automatically detected for all the velocity profiles measured inside the pit.

RESULTS

Applying the methodology explained above, bed geometry along the model was determined in different times by measuring velocity profiles and interpreting them, Figure 5. The evolution of the dredging pit was investigated under different discharges. The pit location for Q_{50} (model) at different instances is shown in Figure 6. As it can be seen the upstream face of the pit remains parallel to its initial slope (1:1). Figure 7 shows the evolution of the dredging pit in the physical model.

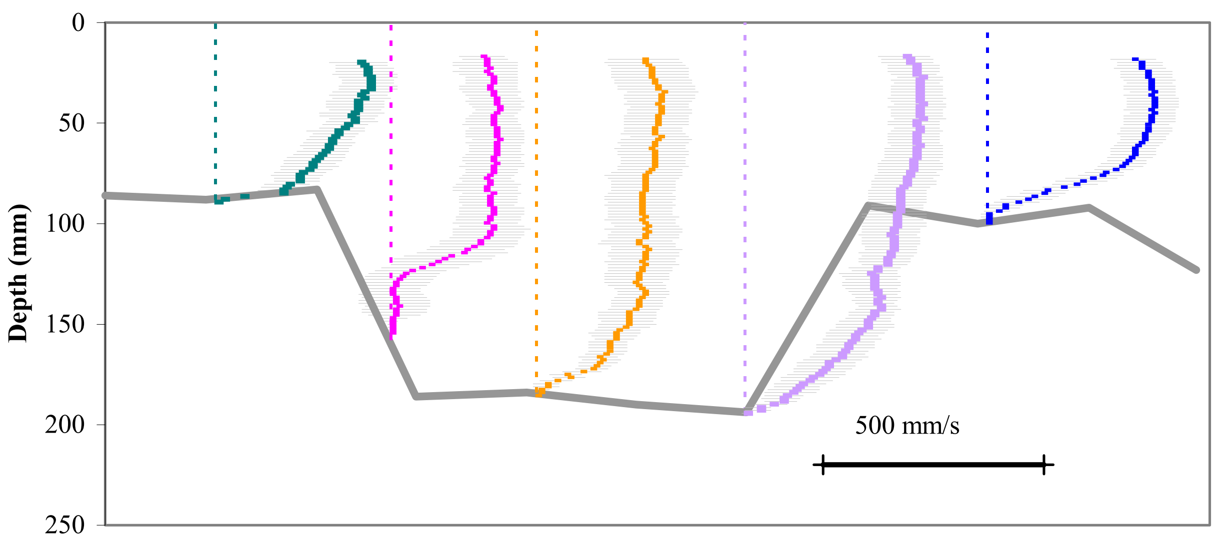

Figure 5: Velocity profiles and standard deviation measured by UVP probes in the pit

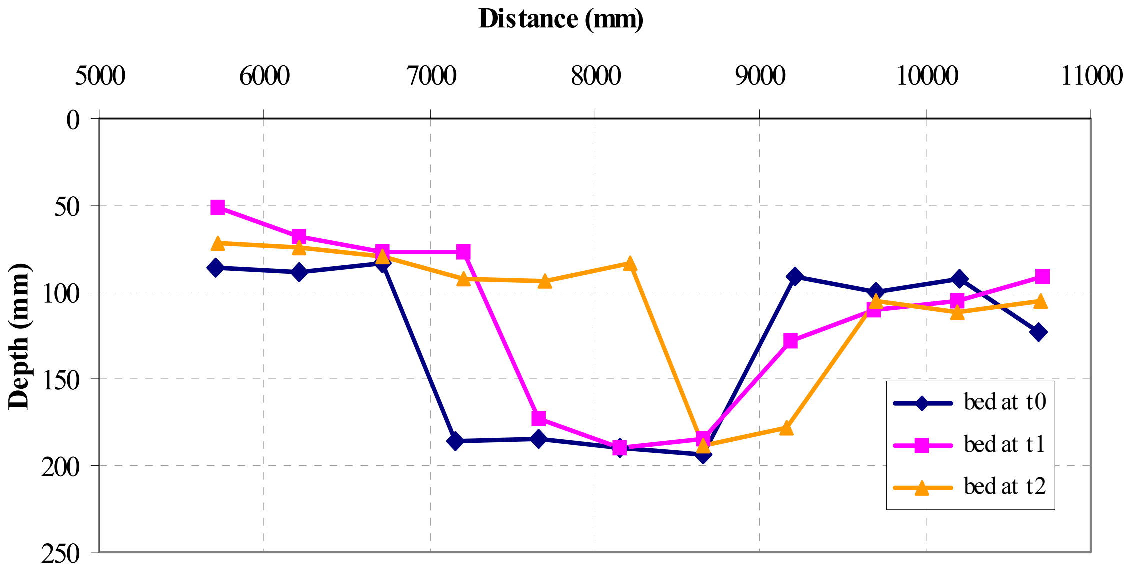

Figure 6: Bed geometry measured by UVP probes at t_1=0, t_2=1 and t_3=3 hours for Q_{50}=54.5 l/s (prototype 740 m^3/s)

Time increasing erosion is observed downstream of the pit. This is due to disruption in the bed load transport, as all the sediments coming from upstream trap in the pit, whereas shear velocity remains the same downstream of the pit and consequently causes erosion. The depth of the erosion decreases towards downstream. It is a transient phenomenon and the extent and depth of the erosion depend on the time required to fill the whole pit by sediments, returning the bed to its equilibrium state. The required time depends on the solid discharge and volume of the pit. Hence, by limiting the size of the dredging zone, the downstream erosion can be controlled with respect to the selected flood event.

Since sediment transport depends on the corresponding shear velocity and sediment size, the pit moves faster with increasing discharge producing higher shear velocity, Table 5. Although the pit moves faster and the required time to fill it is shorter, the downstream erosion does not necessarily decrease as the higher shear velocity causes more erosion in a shorter time.

Table 5. Comparison of the test results for different discharges

Q (l/s)	Pit movement (m/hr)	shear stress τ_o (Pa)	Downstream Erosion extent (m)
42.7	0.20	0.63	6.0
54.5	0.52	0.75	6.9
60.4	1.04	0.88	7.5

Having contraction in addition to the dredging, test results show that local erosion can occur in the pit due to 3-D flow field. Also the shape of the moving pit front is not straight anymore and it advances faster in the center, making a curved pit front.

With a pit size used in this study, downstream erosion on prototype scale can be expected up to 300 m downstream of the pit during major flood events. For the given simulated pit size, dredging operations should take place at least 300 m upstream from any important hydraulic structure (e.g. bridge pier) on the river in order to limit the impact of bed erosion.

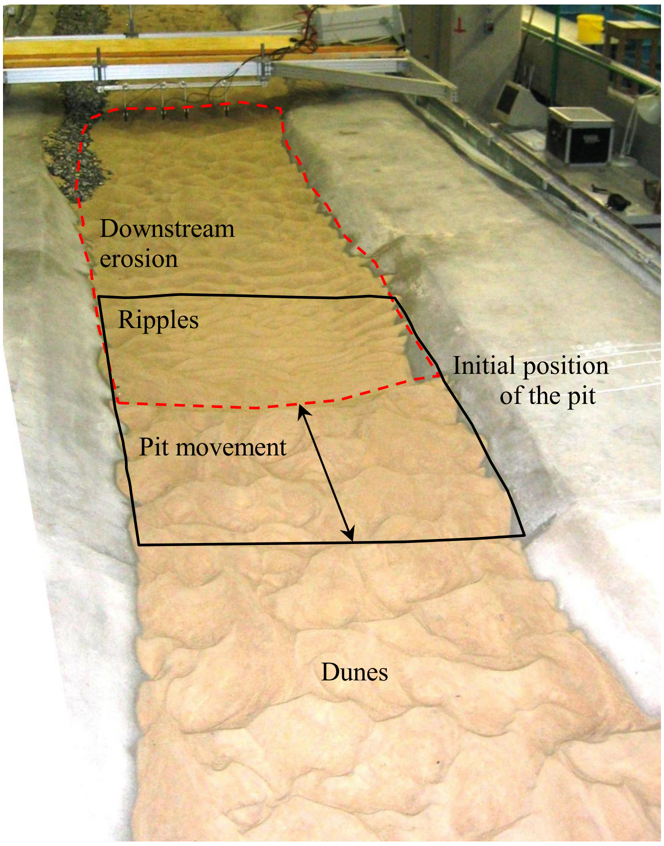

Figure 7: Picture of the pit movement on the river bed

Further investigations are needed in order to asses the effect of dredging pits with other dimensions under different flood events and solid transport conditions.

CONCLUSIONS

A hydraulic model with mobile bed at a scale of 1/45 was constructed to study the effects of a dredging operation on the Rhone River in the Rarogne Region, Canton of Valais, Switzerland. Four UVP transducers mounted on a mobile platform were used to monitor the evolution of the bed geometry and movement of the dredging pit.

Analyzing the average velocity profiles, the possibility of auto bed detection by interpretation of the velocity profiles measured using UVP probed was investigated. In most cases auto detection is feasible. The possibility increases with lower discharges where less bed movement occurs.

Downstream degradation caused by dredging operations was determined for different discharges and recommendations are provided regulating gravel extraction activities.

Further studies are needed to evaluate the effect of different pit dimensions, solid transport conditions and sediment sizes. Numerical modeling, calibrated based on the result of this work, are currently carried out in order to evaluate the sensitivity of the results to effective parameters.

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