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Measurement of the deposition of fine sediments in a channel bed

Sabine Chamoun *,[1], Jessica Zordan [1], Giovanni De Cesare, Mário J. Franca

Laboratory of Hydraulic Constructions (LCH), Ecole Polytechnique Fédérale de Lausanne (EPFL), Station 18, CH-1015 Lausanne, Switzerland

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ABSTRACT

Various instruments allowing the measurements of bottom deposits of fine sediments exist. Different techniques are developed in order to suit diverse operating conditions. The present study considers two high-precision instruments, namely, an electrical resistance-based depositometer (ERBD) and a pulsed red laser diode. Both instruments are described and their parallel calibration process discussed, allowing to evaluate their advantages and their limitations. For this goal, fine sediments are left to settle in a confined experimental tank, and their deposits are monitored using the two instruments. The latter are then compared with the aim of providing guidance and recommendations for researchers dealing with sediment depositions in particular in experimental facilities. The ERBD is then tested in monitoring the deposition due to the passage of a turbidity current and it proved to be a valid and affordable technique to track the space and time evolution of fine sediment deposits. On another hand, the pulsed red laser diode was found to be a user-friendly instrument allowing direct measurements of deposition thicknesses.

1. Introduction

The deposition or sedimentation of suspended material has been the subject of many research works. The estimation of deposition is not an easy task and challenges depend on the circumstances where the measurement is needed. Site specificities constrain the type of instrument that can be adopted and consequently a wide range of techniques were developed and continuously implemented.

The sedimentation process can have impacts on the functioning of hydraulic structures. Examples include the sedimentation upstream of weirs [15] and the sedimentation in reservoirs as presented by [25]. These latter describe many methods for measuring sediment deposition.

The necessity of deposition measurement is also present in industrial flows such as in clarifier tanks and wastewater treatment plants (e.g. [22]; [36]). For instance, the efficiency of a wastewater incinerator can be lowered due to ash deposition and distribution in the heat recovery steam generator as studied by [26]. Non-invasive measuring methods based on an ultrasonic signal reflection technique are used in waste water treatment plants to measure layer deposition of particles which average particle size is around 1 μm [21]. Finally, the electrical admittance is the base principle for measuring the thickness of sludge on the sidewall of a centrifuge in a dewatering system [20].

Additionally, the investigation of deposition is interesting when dealing with geophysical flows in large scale sedimentary basins (e.g. [18]). A particular case of geophysical flows are turbidity currents. These currents are formed when sediment-laden flows coming from the watershed reach reservoirs and lakes. The capacity of turbidity currents to carry sediments depends on many factors but is mostly linked to the turbulence rate of the flow [23]. The amount of particles in suspension affects the dynamics of turbidity currents and therefore their capacity to erode and their depositional rate. For this reason, when evaluating the dynamics of turbidity currents, the investigation of their deposits in time and space is of fundamental importance [12,17,2,23,24,27,28,30,34].

Deposition measurement techniques are in continuous development. [32] measured the sediment level in seawater by using the difference of electrical conductivity while [14] detected sedimentation using LED light sensors. Later, [31] proposed a method for measuring the depositional rates using an optical backscatter instrument. [6] and [16] used a "vacuuming" method in which they siphon up deposited particles at known areas in their tank, dry them and determine its weight. Manual measurements by mechanical probing can also be used. However, non-intrusive measurements are preferred and techniques such as photographic recordings, ultrasonic depth sounders [10], and laser-based instruments (e.g. 3D laser scanners) [1,10,35] were developed.

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* Corresponding author.

E-mail addresses: sabine.chamoun@epfl.ch (S. Chamoun), jessica.zordan@epfl.ch (J. Zordan).

[1] The first two authors contributed equally to this work.

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Nomenclature

C_v	volumetric concentration
d_x	grain size diameter for which x% of the amount of sediments has smaller diameter
e	thickness of the deposit
g	gravitational acceleration
h_w	water depth between reference electrode and bottom electrode
m_s	mass of injected sediments
R_{dep}	resistance of the sediment layer deposited
R_{total}	total resistance measured by the Wheatstone Bridge
R_{water}	resistance of the water column between the reference and the bottom electrodes
S	surface of the cylinder
U	voltage as output of the laser
V_{bulk}	bulk volume of the mixture (water and sediments)
V_s	volume of sediments
v_s	settling velocity
μ	dynamic viscosity of the water
ρ_a	ambient fluid density
ρ_{bulk}	apparent (bulk) density of the sediments
ρ_s	sediment material density

Hydroacoustic techniques were also used by [3] to quantify the bathymetry and spatial distribution of sediment thickness and properties in a lake.

Nevertheless, in literature, most of the studies using different techniques of measurement of fine sediment deposits do not focus on the technical aspect of the instruments but rather on discussing final results they provide. In other words, one can rarely find guidance when getting started with or calibrating a deposition measuring instrument despite the fact that the calibration process is crucial to achieve quality results.

In this paper, two instruments used for measuring the deposition of fine sediments are investigated: (1) a pulsed red laser diode and (2) an electrical resistance-based depositometer (ERBD). The latter has been mainly used in experimental studies [13,29], while the former was used in laboratory and field works. For instance, lasers are used, together with other techniques, to get digital terrain models which are key elements in the accuracy of hydraulic flood modelling [19,8,9]. The goal of this paper is to provide a parallel calibration procedure for the pulsed red laser diode and the ERBD as well as a direct comparison between the two instruments. In a practical point of view, it aims to aid the practitioner and researcher to find the most suitable technique for their specific purpose.

The present paper is structured as such: first of all, both instruments and the sediment material used are described, followed by the calibration set-up and procedure. Then, results of the calibration are discussed and an example of time and space evolution of deposits due to turbidity currents obtained by using the ERBD are shown. Additionally, a comparative table resuming the advantages and limitations of each instrument is given and the measuring errors are discussed. Finally, an overview of the main findings is presented in the conclusions.

2. Instruments description

2.1. Pulsed red laser diode

A Baumer OADM13 laser is used (Fig. 1). It is a photoelectric distance-measuring compact sensor that is typically used in production processes (e.g. for flaw detection in industrial application). It is composed of a laser emitter that produces a light source and a photodiode line working as a receiver. The measuring range of this pulsed red laser diode is of 50–350 mm and it has an accuracy of 0.01–0.4 mm. The distance measurement is based on the triangulation principle: (1) the laser beam strikes an object (2) the receiver converts the backscattered light into a current and (3) an integrated microcontroller detects the position of this point. The angle of incidence changes according to the distance. The controller accurately calculates the angle from the light distribution on the photodiode line and then deduces the distance to the object [5]. A voltage converter translates the current into a voltage signal which is finally sent to the PC. The evolution of the signal in time is shown by a graphical interface which acquires, displays and stores the data.

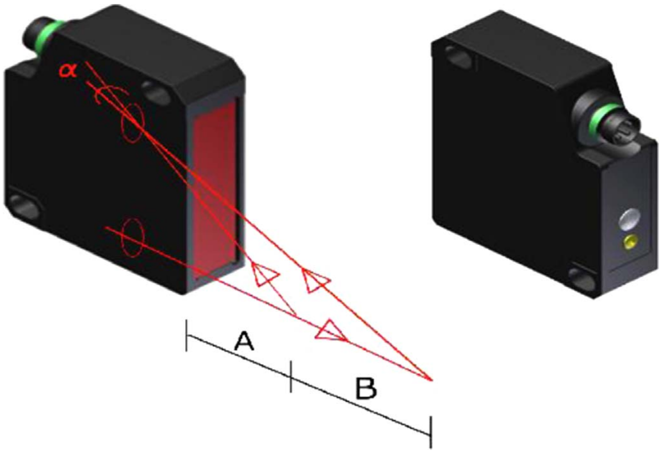

Fig. 1. Laser Baumer OADM13 representing the triangulation principle of the laser beam.

The instrument is placed in a water-proof box, at a known height from the reference bottom. The calibration equation is obtained in experimental operating conditions i.e. with the laser light crossing the transparent bottom of the water-proof box. The measuring range can be adjusted by the user within the maximum measuring range of 50–350 mm (imposed by the factory setting). The analog output has its full span within this range, also called "Teach-in" range. Changing the measuring range causes a variation in the resolution and in the error (deviation between calculated value and measured value due to technical reasons). In other words, the closer the furthest point of the measuring range is to the sensor, the better the resolution and the same goes for having a lower error. The Teach-in feature is designed to choose a smaller range within the nominal measuring range for optimizing the resolution. Two positions must be taught: the first Teach-in position aligns with 0 V (or 4 mA), the second position aligns with 10 V (or 20 mA), therefore the current or voltage output adapts to the new range [5]. Finally, based on the characteristic calibration line of the laser, the output voltage can be linked to the distance of the laser light source to the top of the sediment deposit and consequently, the thickness of the deposit can be calculated [7].

2.2. Electrical resistance-based depositometer (ERBD)

This system is based on a technique developed by [13]. Its main principle relies on the fact that the electrical resistance of a