Flow Measurement and Instrumentation 54 (2017) 197–204

Contents lists available at ScienceDirect

Flow Measurement and Instrumentation

journal homepage: www.elsevier.com/locate/flowmeasinst

Experimental setup for flow and sediment flux characterization at desanding facilities

C. Paschmann*, J.N. Fernandes, D.F. Vetsch, R.M. Boes

Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich, Zurich, Switzerland

ARTICLE INFO

Keywords:
Desanding facility
Sediment trapping efficiency
Prototype measurement campaign
3D flow velocities
Suspended sediment concentration
Particle size distribution

ABSTRACT

Desanding facilities are located between the water intake and the penstock of medium and high-head hydroelectric power plants to avoid the entrance of suspended sediments into the penstock and therefore to reduce hydro-abrasion at turbine parts. This paper focusses on the selection and description of measurement instrumentation to characterize flow and sediment flux at desanding facilities with high spatial and temporal resolution. The selection criteria for the instrumentation are highlighted and the capabilities and limitations of the devices and techniques are described. The modular design of mounting system carrying the instrumentation allows for measurement under several structural constraints. The chosen concept for data acquisition in terms of measurement grid, measurement duration and sampling frequency provides high resolution data of flow quantities and sediment flux. For reliable quantification of sediment fluxes, in-line measurements of turbidity are correlated with suspended sediment concentration obtained by water sampling, also considering density and temperature. Selected findings from the field measurement campaign at two sites in Switzerland are presented and discussed. The employed experimental setup proved to be appropriate and reliable to characterize the flow field and sediment fluxes in desanding facilities at high resolutions.

1. Introduction

The presence of suspended sediments in the turbine water of hydroelectric power plants (HPPs), particularly with medium and high-heads, can entail operational and financial drawbacks due to possible hydro-abrasion at turbine parts [1]. To counter these problems, desanding facilities are typically located between the water intake and the headwater way leading to the turbines in the power house. Desanding facilities aim at reducing the sediment mass as well as the average particle size in the turbine water. For this purpose, sediment-laden water is diverted via an inlet channel into a basin with larger flow area. As a consequence, the flow velocity is reduced, allowing the suspended sediments to settle within the basin. The 'clear' water is then conveyed to the headwater way. The deposited sediments are either continually or intermittently flushed out of the facility and discharged back to the river. A typical design of a desanding facility is schematically shown in Fig. 1. It may include an inlet channel, a transition zone (typically with a divergent channel) and a settling basin.

Various investigations at alpine desanding facilities (e.g [2].) revealed unsatisfactory flow conditions and low particle trapping efficiencies, although the investigated facilities meet current design recommendations as described e.g. by [3,4]. Since the trapping efficiency of desanding facilities is directly related to hydro-abrasion in the turbines, the facility performance represents a key factor for sustainable and economic operation of HPPs.

Within the scope of a research project at the Laboratory of Hydraulics, Hydrology and Glaciology (VAW) of ETH Zurich, enhanced design guidelines for desanding facilities shall be developed based on a composite approach, combining numerical simulations and precedent field measurements. For this purpose, it was aimed at obtaining high quality flow field and sediment flux measurement data in a dense measurement grid and at high temporal resolution from desanding facility prototypes. The facilities *Saas Balen* and *Wysswasser* (both located in canton *Valais*, Switzerland) were selected for this investigation.

The present paper describes the measurement instrumentation, the specific measuring methods and specifications as well as the composition of the modular and flexible setup for the field measurements. Moreover, the paper delineates the experiences gained with this novel combination of various instrumentation used to monitor flow and sediment characteristics with high temporal and spatial resolutions in desanding facilities. The measurement setup was designed to record 3D flow velocities as well as sedimentological parameters. The latter comprise turbidity, density and temperature of the water-sediment

* Corresponding author.
E-mail address: paschmann@vaw.baug.ethz.ch (C. Paschmann).

http://dx.doi.org/10.1016/j.flowmeasinst.2017.02.010
Received 21 April 2016; Received in revised form 22 November 2016; Accepted 5 February 2017
Available online 07 February 2017

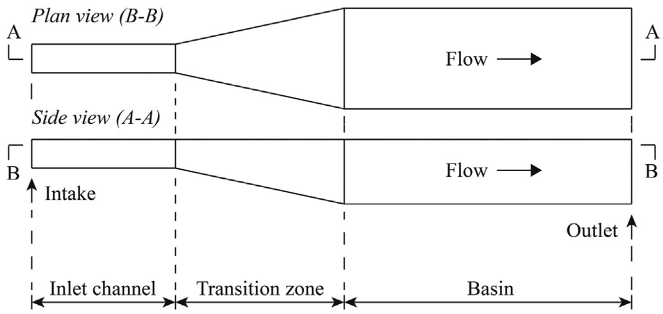

Fig. 1. Schematic illustration of a typical desanding facility geometry.

mixture. Furthermore, numerous water samples were taken to determine the suspended sediment concentration (SSC) and particle size distribution (PSD) in the laboratory. The main results obtained within the measuring campaign are presented in order to provide information regarding the applicability and consistency of the measurement setup.

2. Measurement concept

Desanding facilities are typically composed of (i) an intake structure, (ii) an inlet channel diverting the water towards the basin, (iii) a transition zone with continuous increase of flow area and (iv) a basin along with (v) an outlet structure at the end. For the description of the flow and the sediment fluxes in these facilities, the measurement concept was developed to obtain high-resolution measurement data of flow velocity, turbidity, density and temperature of the water-sediment mixture in a dense measurement grid throughout the basin, as well as supplementary measurements of flow velocity and turbidity in the inlet and in the outlet areas. The density measurements allow for correlating density and SSC especially at higher SSC values to supplement the correlation of turbidity and SSC. Beside those direct measurement techniques, numerous water samples were taken to determine (i) the SSC by weighing the dried residue and (ii) the PSD by using a laser particle size analyzer in the laboratory. This is a common procedure to find a correlation between measured turbidity and SSC as well as to determine the PSD.

The applied measurement instrumentation comprises (i) acoustic Doppler velocimeters (ADV), (ii) turbidity sensors, (iii) radar sensor, (iv) Coriolis flow- and density meter (CFDM) and (v) automatic bottle sampler. The devices are shown in Fig. 2 and the technical specifications are subsequently described in detail. The names of the devices and manufacturers are mentioned for information purposes only.

3. Instrumentation

3.1. Acoustic Doppler velocimeters

Nortek Vectrino+ ADVs with side-looking head and flexible cable stem were used for the 3D flow velocity measurements. The maximum frequency is 200 Hz and the nominal measurement accuracy is ± 0.001 m/s ± 0.005 times the measured velocity components.

The ADV measuring principle is based on the Doppler effect. The (stationary) ADV probes emit a signal of known frequency which is partly reflected by particles passively transported in the flowing water. Consequently, the flow velocity is computed based on the recorded frequency shift between the emitted and the received signal [5]. It is therefore assumed that particles and water have the same velocities. To obtain spatial velocity information, the instrument has one beam for each velocity component and an additional fourth beam (not used with side-looking probe design) for an independent measurement of the vertical flow velocity component. The signals are internally processed and combined by taking the probe orientation in the water into account.

Restrictions can occur when no particles are present in the flow, or at very high suspended sediment concentrations. In the former case, the signal cannot be reflected, whereas in the latter case the overall signal absorption at the particle surfaces is too high, leading to no signal reflection.

In view of the range of application, ADV measurements are reported to be very suitable for velocity measurements in free surface flows [6], showing the same level of accuracy regarding the determination of mean flow velocities as laser Doppler velocimetry, ascertained based on laboratory investigations [7,8]. express the possibility to measure turbulence and capture the major fraction of the turbulent kinetic energy (TKE) due to the high temporal resolution of ADV measurements. This was validated by investigations of [9].

The employed ADV probe model was on the one hand selected based on laboratory experiences, in-house expertise and availability. On the other hand, laboratory investigations of [10] comparing three different ADV systems found the Nortek Vectrino to perform very reliably under various conditions. The noise level, the response to device tilting as well as the disturbance onto the flow field was lowest, whereas the signal-to-noise ratio (SNR) as a measure of quality was consistently highest for the investigated cases.

The capability of performing measurements in turbid water due to the lower deterioration of the acoustic compared to the optical transmission [7] is advantageous for the application of ADVs in desanding facilities [2]. presents the general capability to conduct high-quality ADV measurements at alpine desanding facilities by means of a measurement campaign realized at prototype scale.

3.2. Turbidity sensors

Turbidity sensors CUS52D of Endress+Hauser have been used for real-time and continuous water turbidity measurements. The measuring principle of these optical sensors is based on 90° light scattering, which is more sensitive than other measuring principles to a variation of particle characteristics like size and shape [11]. The nominal measurement accuracy is 2% ± 0.01 FNU (Formazine Nephelometric Units). Using similar optical backscatter devices, investigations of e.g [11–13]. indicate a reliable use in the measurement of SSCs up to several g/l.

In an overview summarizing numerous techniques regarding SSC measurements [14], mention the approximately linear correlation between optical backscatter and SSC at constant conditions, and the high temporal measurement resolution as advantages of such sensors. In contrast, the dependency on particle color, shape and especially size of the suspended sediments [11] is disadvantageous for the correlation between turbidity and SSC in natural waters.

Based on a field study [15], demonstrate the influence of particle shape on optical turbidity measurements. Although showing almost the same mass-related median diameter at the testing conditions, flaky mica particles induce around four times higher turbidity readings than glass spheres.

Following [16], optical turbidity sensor readings are greatly affected by changes in particle sizes below 100 µm, but minimally affected in a particle size range of 200–400 µm. Similar results were obtained by laboratory investigations of [11]. For synthesized water-sediment suspensions with identical SSC composed of different sands (d_{50}=107–430 µm), silt and clay (d_{50}=40 µm), the response of the examined optical turbidity sensors increased considerably with increasing proportion of silt and clay in the suspension.

Conducting measurements at constant discharge conditions and permissibly assuming virtually constant particle shapes and colors in the catchment area and similar size distributions in the flow during the measuring campaign, the previously mentioned constraints can be minimized. In order to safeguard turbidity measurements, particle size analyses should be conducted in addition [16].