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“Paddan” sight-seeing boat in Gothenburg
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River intake and desander efficiency testing on a physical model using UVP and LSPIV

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Hydraulic model tests were carried out in order to establish the feasibility of the Teesta VI hydropower plant in Sikkim State, Northern India. An initial arrangement of barrage and river intake with four desander basins on the right bank of the Teesta River, tributary to the Brahmaputra, has been proposed. During high Monsoon floods, river bed load and suspended sediments shall be diverted through the spillway openings. During normal operation, the four desander basins of 250 m lenght with free flow conditions must be able to evacuate suspended sediments avoiding their entrainment into the power intakes. In order to study flow conditions and evaluate the river intake and desander design, LSPIV and UVP measurements were performed at several locations within the basins and the intake zone. The measurements were conducted for two different river intake designs. UVP allowed to measure mean flow velocity and evaluate the retention efficiency of the basins. Overall flow field comparisons for different scenarios over the entire model surface are reported by LSPIV technique.. The mean flow velocity is the main parameter to design a desander and it is directly related to the sediment grain size diameter to be removed. To improve the desander efficiency, flow disturbances as reverse flows, circulation cells and eddies must be avoided. Therefore the flow velocity must be well distributed all over the cross section and the flow velocity standard deviation must be minimized.

Keywords: Hydraulic model tests, run-of-river power plant, river intake, desander, UVP, LSPIV

1 INTRODUCTION

The 500 MW Teesta VI hydropower project, located on the Teesta River in southern Sikkim, India, is a run-of-river scheme. It is the last stage of the Teesta Cascade development within the state of Sikkim. Hydraulic model test have been carried out at the Laboratory of Hydraulic Constructions (LCH) of the Ecole Polytechnique Fédérale de Lausanne (EPFL). The model includes a part of the upstream river section, the barrage with the four spillway passages, the river intakes and the four desander basins, two power intakes, and a part of the downstream river (Figure 1).

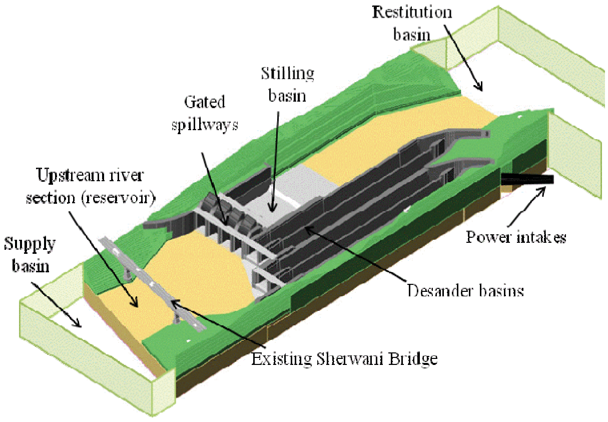

Figure 1: Boundaries and components of the physical model in its original river intake configuration.

The main purpose of the hydraulic model tests was to assess the viability of the arrangement of barrage, desanders and power intake. During high Monsoon floods, river bed-load and suspended sediment shall be diverted through the spillway openings placed at riverbed level. The mentioned head works consist of the following structures:

- dam with gated spillway (concrete structures);
- upstream river intakes on the right bank with four subsequent sediment settling basins (desanders)
- and power intake arrangement after the desanders with 2 head race tunnels.

In order to reduce the erosion wear at the guide vanes and runners of the turbines, desanding basins have to be provided. They were designed and dimensioned on the principal of a reduction of the water velocity that helps sediment particles to settle down. In this paper, special attention is given on the river intake design (orientation, form, etc.) and the desander basin size. The flow conditions have been assessed using Large-Scale Particle Image Velocimetry (LSPIV) and Ultrasonic Doppler Velocity Profiler (UVP) measurements. These techniques have been successfully applied in previous research studies by Kantoush et al. (2007) [1], Kantoush and Schleiss (2009) [2] and in general hydraulic modeling by De Cesare and Boillat (2008) [3] and Bieri et al. (2009) [4].

2 MODEL SETUP AND INSTRUMENTATION

2.1 Scale and main parameters

With respect to the objectives of the study, the size of the model and considering the similarity rules and possible scale effects, the comprehensive model has been constructed with a scale factor 1:75. It was operated with respect to Froude similarity, i.e. conserving the inertial and gravity forces ratio. The overall model covered a surface of 2.80 x 10.30 m^2. The maximum discharge for the Standard Project Flood (SPF) is 11’600 m^3/s at prototype scale. The design discharge for the hydropowerplant (HPP) is 531 m^3/s separated into four desander basins, two power intakes and headrace tunnels.

2.2 Instrumentation

Several parameters were measured during experimental tests, namely: 2D surface velocities, velocity profile in water column, water levels and discharge. The physical characteristics which were measured on the model and the corresponding instrumentation are summarised in Table 1.

Table 1: Main measuring devices and accuracy

Parameter	Instrumentation	Accuracy
Water level	Manual limnimeter	0.5 mm
Velocity profile	Ultrasound Velocity Profiler (UVP)	1 mm/s
Surface velocity field	Large Scale Particle Image Velocimetry (LSPIV)	1 mm/s
Pressure	Dynamic pressure transducers/piezometers	0.1 mm, 128 Hz sampling freq.
Discharge	Electromagnetic flowmeter	1% of max. capacity

The surface velocity field of the approach flow to the gated spillways and to the desanding basins were assessed using LSPIV technique. A Met-Flow SA UVP with a single 2 MHZ transducer has been used for the measurement of vertical velocity profiles at the intake axis as well as inside the desander basins at an angle of 30°. The number of channels was 220 inside the desander, 1024 profiles were taken to get average velocity and standard deviation per channel, the sampling time per profile was 64 ms.

3 RIVER INTAKE AND DESANDER DESIGN

The river intake is the most upstream element for run-of-river hydropower production. Its objective is for the powerhouse design discharge, regardless of river discharge, to ensure uniform water derivation over the width and water depth, to keep the entrance free from bed load and floating debris, and to present a homogeneous flow velocity at the trash rack section. Large eddies in the river approach zone should be prevented from entering the desanders, swirling flow at piers and upstream dead zone should not occur during normal flow conditions. The flow inside the desander should be as homogeneous as possible to allow an efficient sediment settling process. For general design criteria and example details for desilting chambers see Ortmanns and Minor 2007 [5].

The following tests have been performed on the physical model:

- Verification of approach flow conditions, occurrence of flow separation and vortex formation inside and upstream of the river intake;
- Study of the approach flow in front of the desander basins, considering the possibility of reverse currents and eddy formation;
- Investigation of the velocity distribution and approach flow conditions at each water intake opening and discharge distribution between the four openings;
- Verification of the flow and eddy formation inside the desanders.

The discharge has been fixed at half the powerhouse design discharge (531 m^3/s) per power intake and pair of desanders.

The overall flow behavior can be determined using LSPIV. The CMOS camera has been fixed some 3 m vertically above the model. Seeding was obtained by means of white plastic particles, with an average diameter of 3.4 mm and specific weight of 960 kg/m^3.

Figure 2 shows the surface velocity field for the upstream river section, water intake and desander basins for regular operation (design discharge and normal water level).

The angle between main approach flow and intake axis is at the origin of a non uniform discharge distribution. Desander 1 and 2 take more discharge, desander 3 functions below its design discharge. Any non uniform velocity, respectively discharge distribution lowers the efficiency of the entire desanding system.

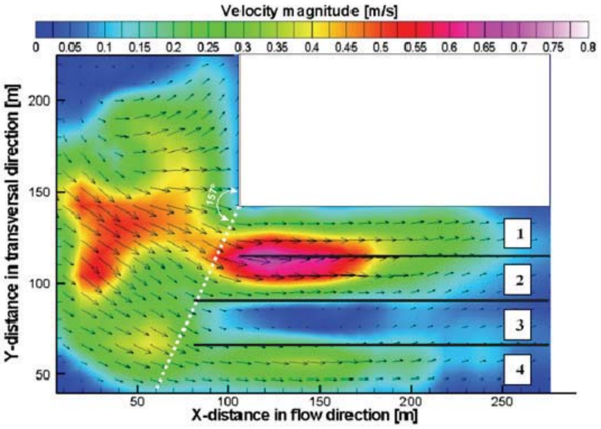

Figure 2: Average flow pattern with surface velocity vectors by LSPIV for the initial intake design (Q = 531 m^3/s, water level 360 m a.s.l.). Note that desander 3 has very low velocities inside.

Vertical velocity profiles were taken at the intake axis and inside the desander chambers (Figure 6). Hydrogen bubble seeding was used to obtain good US echo. This technique has been proven to be very efficient in physical scale modeling by Meile et al. 2007 [6]. The seeding installation can be seen in Figure 4 placed at the intake to desander 3.

Three profiles were measured at the intake section in order to determine by surface integration the discharge passing through. Table 2 summarizes the discharge distribution. One can clearly see that especially desander 3 has a very low discharge compared to desander 4, which has therefore a reduced sediment settling efficiency. The discharge distribution is 43/57%, ideally it should be 50/50%.

The velocity profiles taken inside the 26 m deep desanding chambers show not only a non uniform distribution over the water column (and basin width), but also a rather high turbulence (see Figure 6, left below), which again leads to inefficient particle settling.

The main reasons for the malfunctioning are the orientation of the intake axis, creating a local detachment of the water flow and the four large entry sections. The original design with its large entry sections allowed eddies of the size of the intake width and smaller turbulent structure entering easily the desander basins thus reducing considerably their sediment trap efficiency.

4 MODIFIED RIVER INTAKE

The presence of a vortex at the entrance of the desanders, the disparity in discharge distribution between desanders, the turbulent flow inside the desander basins and the need of a larger width to install a trash rack led to a modification in the design of the water intake.

Based on the results of the previous chapter, the design engineers together with the research engineers of the EPFL-LCH proposed a modified river intake design.

The entrance section was oriented towards the main flow direction, it was enlarged and divided into three passages and then narrowed into the entrance of the desanders as shown in Figure 3 and 4.

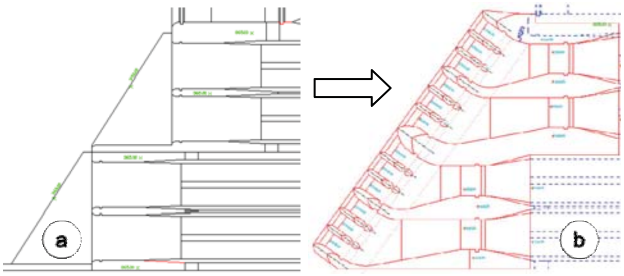

Figure 3: From initial (a) to the optimized (b) river intake design and transition to the desander basins.

The narrow passage prevents large eddies to enter the desander. The local contraction in width and depth (there is a small sill) between intake and desander with its streamline convergence prevents even small transversal flow turbulences from entering the desander.

Figure 4: New intake set-up for desanders with UVP and hydrogen bubble seeding installation for velocity measurements.

Figure 5 shows the surface velocity field for the upstream river section, new water intake and desander basins for regular operation obtained by LSPIV. The approach flow is well oriented and the velocity distribution at the entrance section of the desander chambers is improved compared to the previous design.

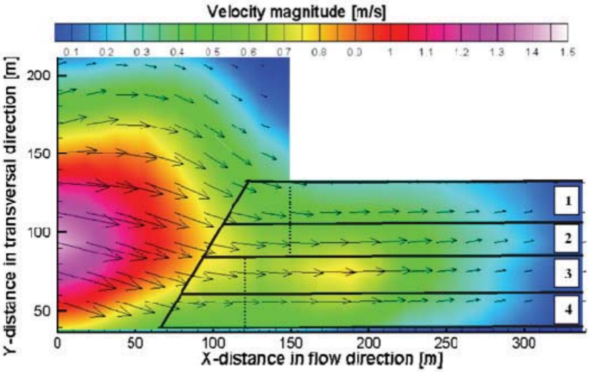

Figure 5: Average flow pattern with surface velocity vectors by LSPIV for the modified intake design (Q = 531 m^3/s, water level 360 m a.s.l.).

Figure 6b) and d) show a uniform velocity distribution both at the intake section and inside the desander chamber. Due to the reduced width of the intake section because of the two intermediate piers, the average velocity is higher, but a very homogeneous velocity distribution over the width and depth of the intake section results.

The velocity fluctuations inside the desander chamber are significantly reduced; see Figure 6c) and d) while the average velocity is increased due to the higher discharge.

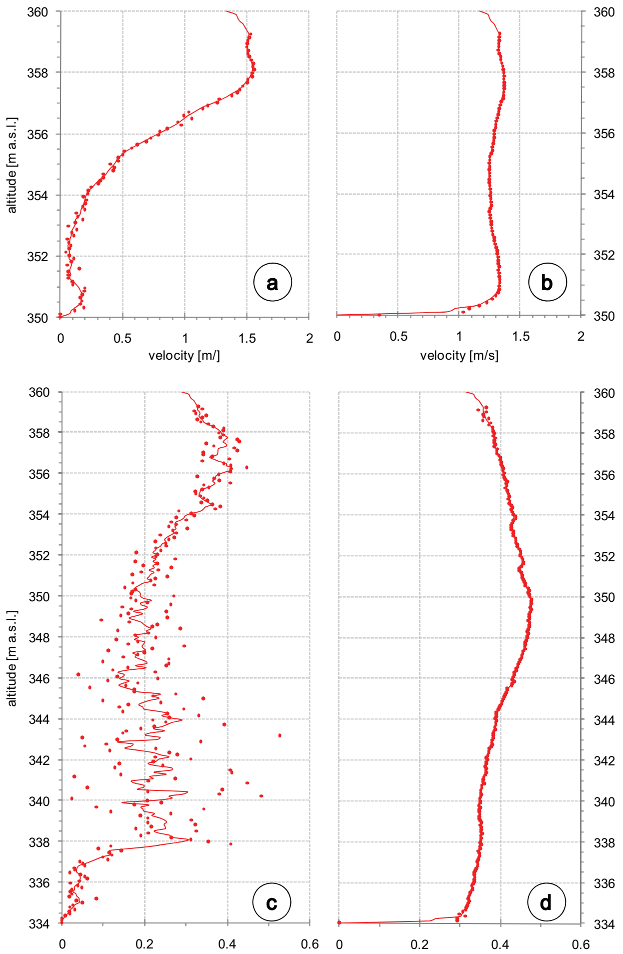

Figure 6: Velocity profiles at the rive intake N° 3 axis (a and b) and in the middle of the corresponding desander basin (c and d) for the original (a and c) and optimized (b and d) intake design ($Q = 531\ m^3/s$, water level 360 m a.s.l.).

Again three profiles were measured at the intake section in order to determine the discharge by integration. Table 2 summarizes the discharge distribution for both old and new design.

Table 2: Discharge distribution between the 4 intake bays to the desander basins for the initial and optimized intake design. The discharge has been fixed per power intake, desander pair 1 and 2, resp. 3 and 4 together to half of the powerhouse design discharge of 531 m^3/s.

Basins	Initial intake design		Optimized design	
	m^3/s	%	m^3/s	%
1	121.8	45.9	129.8	49
2	143.7	54.1	135.7	51
1+2	265.5		265.5	
3	114.5	43.1	132.0	50
4	151.0	56.9	133.5	50
3+4	265.5		265.5	
Total	531.0		531.0	

Compared to the initial geometry, the discharge distribution with some 49/51% is nearly perfect for the desander pair 1 and 2 and 50/50% for 3 and 4. This is a remarkable result for an uncontrolled intake structure.

6 SUMMARY AND CONLCUSIONS

The headworks are a crucial component of any run-of-river hydropower project. These structures have to allow extracting the powerhouse design discharge properly minimizing problems cause by sediments in intake, settling basin and the flushing structures. Therefore special attention is required on layout and design of headworks.

Thanks to LSPIV and UVP measurements, the physical tests allowed putting in evidence the limits of the initial design and proposing a new river intake design which avoids uneven discharge distribution among desander chambers. Furthermore, this new design improves the flow conditions inside the chambers permitting a better functioning of the entire system.

In conclusion, the limitations of the initial design were identified during the physical model tests. Modifications were duly addressed which resulted in an improvement of the final design of the Teesta VI headworks.

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