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## Flow investigations for fish pass Lauffen/Neckar in field and laboratory

Béla Sokoray-Varga\*, Roman Weichert\*\*, Boris Lehmann\*

The present study deals with ADCP fixed-boat measurements carried out in the outflow region of a hydro power plant in the river Neckar, where the entrance of a new fish pass is planned. The investigated region is characterized by highly turbulent flow influencing the ADCP data quality. The applied methodology of capturing the mean velocity field is presented, with considerations on filtering possibly erroneous samples using the “error velocity” value.

Die vorliegende Studie befasst sich mit ADCP-Punktmessungen, die im Nahfeld des Saugrohraustritts der Wasserkraftanlage Lauffen am Neckar gemacht wurden. An dieser Stelle ist der Einstieg einer neuen Fischaufstiegsanlage geplant. Der untersuchte Bereich ist durch hochturbulente Strömungen gekennzeichnet, welche die Qualität der ADCP-Aufnahmen beeinflussen. Die angewandte Methodik zur Erfassung der mittleren Fließgeschwindigkeiten wird vorgestellt, mit Überlegungen zur Filterung von eventuell fehlerhaften Proben durch den „error velocity“-Wert.

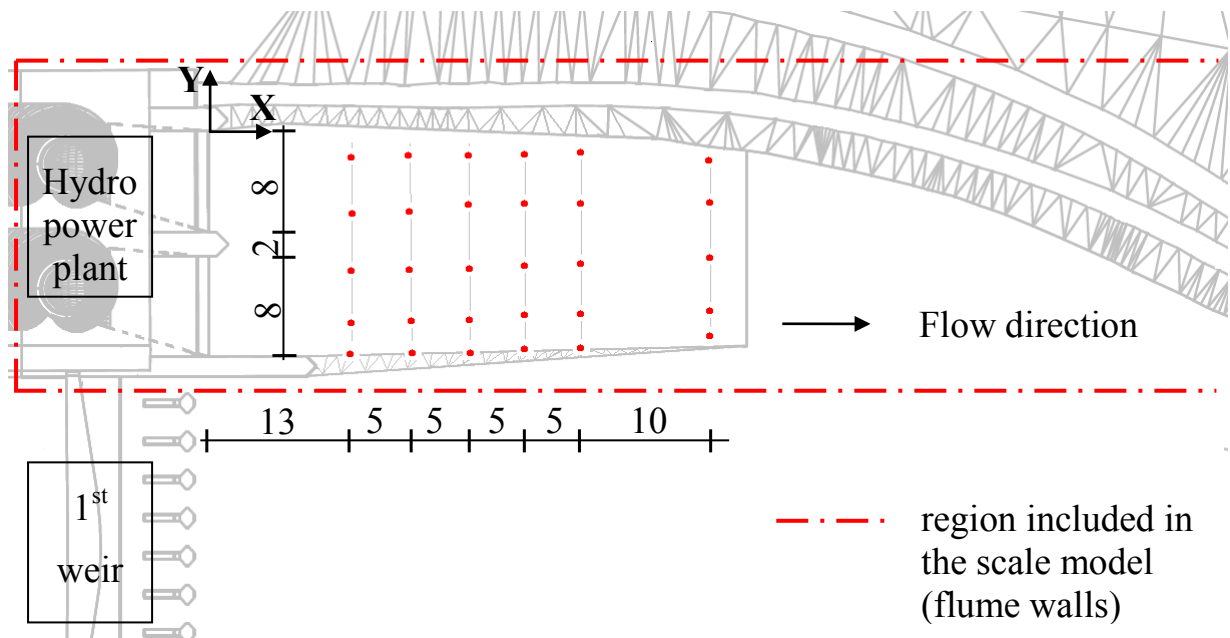
### 1 Introduction

One of the most challenging tasks in designing fish passes is to develop a fish pass entrance region with an effective fish attraction level. Guidelines recommend placing the entrance of the fish pass as close as possible to the outflow of the hydro power plant. So, considering the near-field attractivity of the fish pass, fish have to be able to locate the entrance beside the strong and highly turbulent current of the hydro power plant while the flow rate from the fish pass entrance is relative small. An important basis of the orientation for fish migrating upstream is the detection of the mean flow. The near-field attractivity can be consequently achieved by producing appropriate hydraulic conditions so that the entrance is detectable by fish.

In a current project of the Federal Waterways Engineering and Research Institute (BAW) attractivity issues of a planned fish pass in the river Neckar at Lauffen are studied using a laboratory model and field measurements. The

entrance of the fish pass is planned to be located on the left bank next to the outflow of the hydro power plant (Figure 1). The investigations aim to achieve effective hydraulic conditions in the entrance region, so that the outflow of the fish pass is detectable for fish migrating upstream.

The main focus of the investigations is to study the hydraulic conditions at the confluence of the outflow from the fish pass and the current of the hydro power plant in a laboratory model with a scale of 1:10. As only the investigation of the near-field situation was scheduled in the setup for the scale model, the approximately 100 m wide weir field of the barrage and the right bank were not included in the model. In order to achieve a good representation of the natural flow in the model field measurements have been carried out. These are intended to be used as validation data for the model.



**Figure 1** Plan view of the modelled region, borders of the scale model, and the locations of the ADCP fixed-boat measurements (units: meters in prototype).

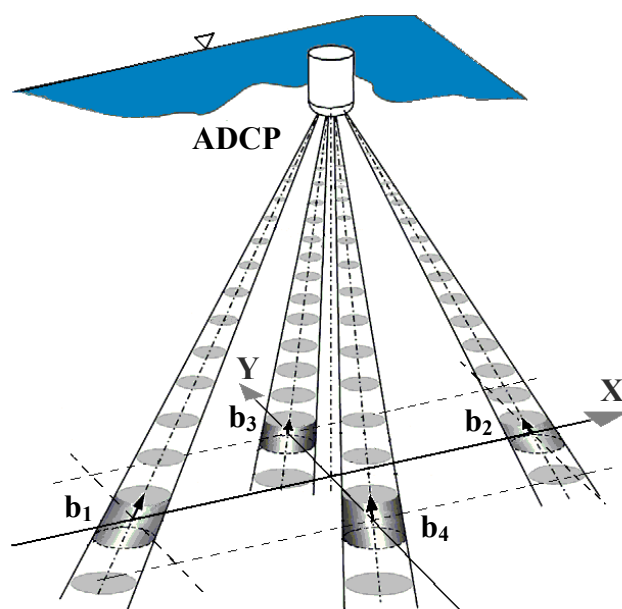
An ADCP (Acoustic Doppler Current Profiler) has been used to capture the mean velocity field in the investigated region by doing fixed-boat measurements (e.g. Muste et al. 2004b, Baranya 2010) at the locations indicated in Figure 1.

The ADCP measurements were carried out during a week where a discharge of about  $45 \text{ m}^3/\text{s}$  flew through the hydro power plant and no flow over the weirs. During the measurements the ADCP was mounted on a standard vessel that was held at the locations indicated on Figure 1 by ropes. This is not a rigid fixing, a displacement of the vessel could occur in vertical sense due to water surface level variations and to some extent also in horizontal sense due to the surface velocity variations. A DGPS was used to provide a velocity reference.

## 2 Some considerations on ADCP measurements in turbulent flow

The investigated region is situated next to the outlet of the turbines and is therefore characterized by high turbulence and flow structures of different time and length scales. Such flow characteristics cause disturbances in the horizontal homogeneity of the flow velocities, and may weaken the accuracy of the ADCP measurements. Data obtained from such flow conditions need to be examined with respect to the possible measurement errors.

ADCP is an acoustic water current meter that can measure the 3-dimensional flow velocities in depth cells along a water column. To get the 3D velocity vector the applied ADCP uses four acoustic beams as shown in Figure 2 (for detailed descriptions see RDI 2006). As acoustic sensors are only able to measure the beam-axis components of the velocity, the reconstruction of the 3D velocity vector occurs in two consecutive steps. First is to measure the beam-axis velocity components in the four different sampling volumes (Figure 2), and second is to combine the measured beam-components to a 3D velocity vector. Accordingly, one pair of beams allows the reconstruction of one horizontal and the vertical components, and using two pairs' results in two independent measurements for the vertical component.



**Figure 2** Beam geometry of the used ADCP (after Muste et al. 2004a) showing the sampling volumes of a depth cell and the corresponding beam-components

Each beam is performing its own measurements along its own axis. Due to the beam inclination the beams are sampling in volumes that are located horizontally further away from each other as the sampling depth increases.

During the reconstruction of the 3D velocity vector data from all four beams are used, so that the velocities in the four sampling volumes are practically averaged during the process and a type of spatial average is generated. The reconstruction is done using a trigonometric beam-to-orthogonal transformation (RDI 2010):

$$U = \frac{1}{2 \cdot \sin \varphi} (b_1 - b_2); \quad V = \frac{1}{2 \cdot \sin \varphi} (b_4 - b_3); \quad W = \frac{1}{4 \cdot \cos \varphi} (b_1 + b_2 + b_4 + b_3),$$

where  $b_i$  are beam-components, and  $U$ ,  $V$ ,  $W$  orthogonal components (Figure 2).

The trigonometric reconstruction is correct only if the flow velocity distribution is horizontally homogeneous. Even one sampling volume with deviant velocity affects at least 2 orthogonal velocity components. As an indicator for non-homogeneous velocity distribution the so called “error velocity” is delivered by the instrument for every sample in each depth cell (RDI 2010), involving the horizontal components from all of the four sampling volumes as:

$$e = \frac{1}{\sqrt{2} \cdot 2 \cdot \sin \varphi} (b_1 + b_2 - b_4 - b_3)$$

A threshold value for the error velocity can be set in the ADCP, so that samples collected with a too high value are filtered out during the measurement.

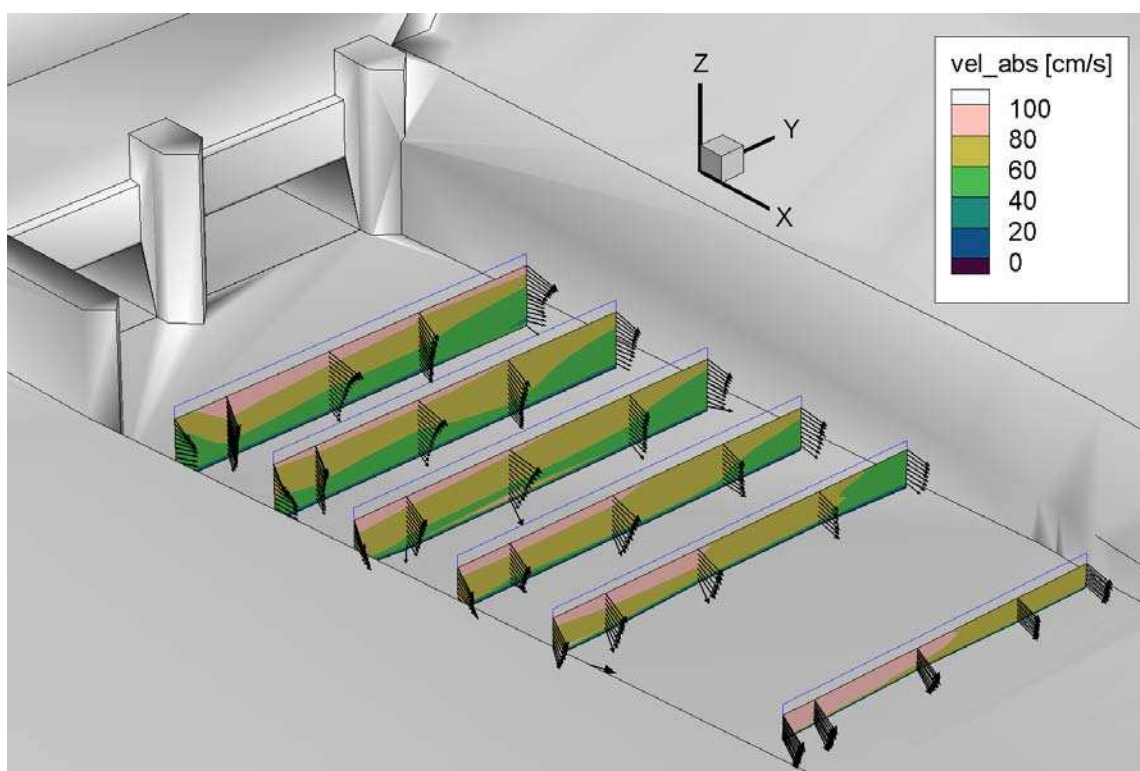
The flow characteristics in the investigated flow region constitute flow conditions where a large amount of erroneous samples were expected during the measurements. The strategy of the field survey was therefore to measure at the highest possible sampling rate, to allow the recording of even suspicious vectors and to filter the measured values within a post-processing step. Accordingly, the error velocity threshold was set to the relative high default value of 2 m/s so that the collection of less accurate samples was allowed.

For an adequate description of the mean flow velocity data has to be collected over a sufficient sampling time length while the instrument is held at the same location (fixed-boat measurement). Collecting long enough, the derived statistical features become stationary. This is usually verified by inspecting the stability of statistical features as a function of the sampling time length e.g. the cumulated mean function of the velocity, or the normalized mean square error function (Muste et al. 2004b, Gonzalez-Castro et al. 2000).

The sampling rate can not be specified directly for the ADCP as the processing cycle of one sample includes signal processing and data transmission times depending on the number of depth cells (RDI 2006). The processing cycle time can be reduced by selecting suitable sampling settings, for example reducing the cell number. In case of the maximal water depth of 4.2 m and a cell depth of 20 cm the number of cells could be reduced to 22 (instead the default of 30). The blank time between pings was also reduced to 5 ms.

### 3 Analysis and results

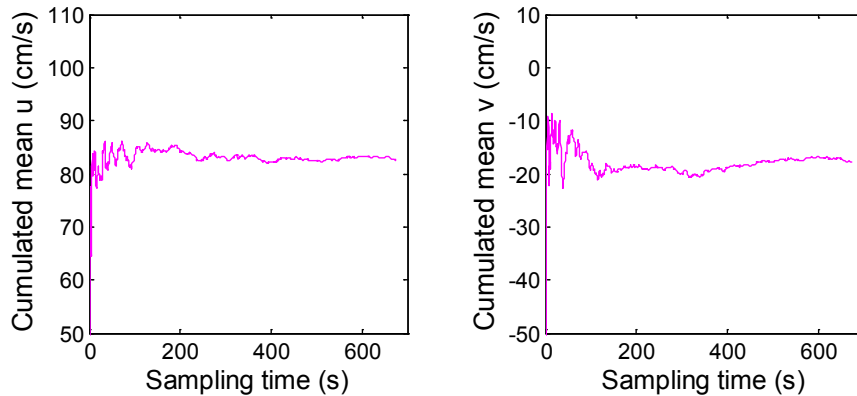
The water depth varied between 2.5 m and 4.2 m in the investigated region, as the bottom level has a constant gradient elevating in flow direction. Due to the beam-geometry the instrument could not deliver vectors from the lowest depth range of 1.2 m. The first measured depth cell from the water surface was at 0.51 m depth. The instrument could reach a sampling rate of about 4.5 Hz in all of the locations. The sampling time interval was set to 10 minutes.



**Figure 3** The mean velocity vectors with the distribution of the magnitude of the 3D velocity vectors

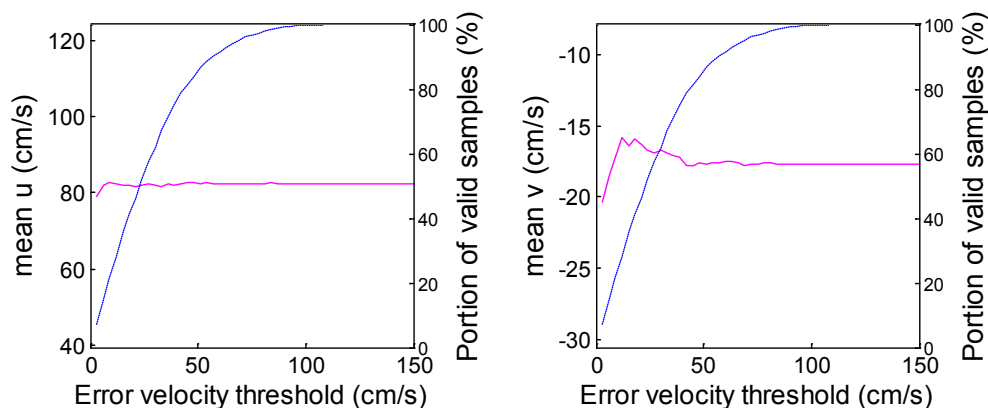
The resulting mean velocity vectors of the measured depth cells and the interpolated fields of the velocities (Figure 3) show a plausible distribution both along the verticals and in the cross-sections. The ADCP classified most of the samples as valid and only 1-3 % as erroneous, although the flow was highly turbulent and large quantities of air bubbles were in the flow according to visual inspection. In order to examine the quality of the records, the data of each depth cell was examined. The steps of the examination are described in the following demonstrated on an example depth cell from the cross-section nearest to the outlet. Note that the measured ranges of the vertical velocity components were an order of magnitude smaller than those of the horizontal ones; so the vertical component is not discussed in the following analysis.

The cumulated velocity functions (Figure 4) showed that the 10 minutes sampling time length was long enough for the vast majority of the profiles, only some depth cells near the outlet seem to require some additional sampling time.



**Figure 4** Sensitivity of the velocity against the sampling time length

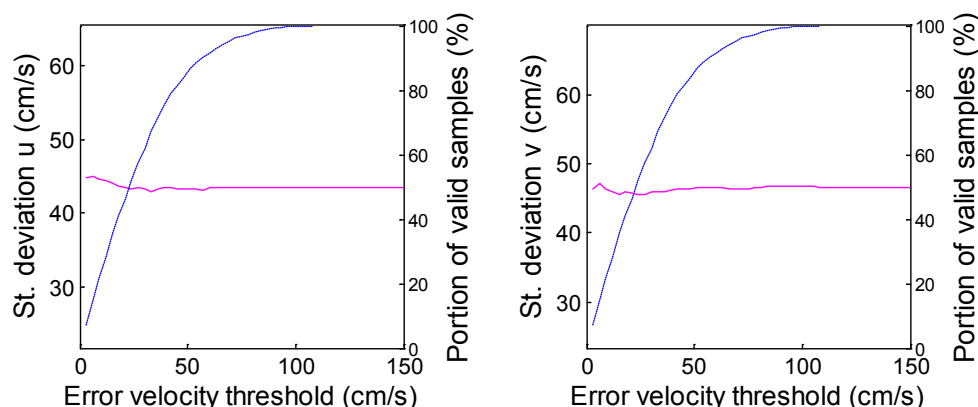
As the default error velocity threshold was used during the measurements, samples of lower accuracy (hence higher error velocity value) may also be among the data. To examine the possible influence of such samples on the quality of the data, the sensitivity of the mean velocity against the error velocity threshold was examined (Figure 5). One can observe that reducing the threshold removes samples having high error velocity values, and the rate of the valid samples (dashed line) is reduced. At the same time this modifies the value of the mean velocity (solid line), and is consequently a relevant parameter. For the specification of an acceptable threshold, the local flow characteristics should also be taken in account, since different turbulence levels probably allow different tolerances.



**Figure 5** Sensitivity of the mean velocity against error velocity threshold (solid line: mean value; dashed line: portion of valid samples)

The use of the standard deviations calculated from the measured horizontal components was examined as a possible threshold for the error velocity. A

threshold for a filter is required to be more-or-less invariant against the filtering process, so the sensitivity of the measured standard deviation was inspected against error velocity threshold (Figure 6). The inspection showed no significant sensitivity. Note that the values of the standard deviations in  $X$  and  $Y$  directions were only little differing, and their values generally lied between 30 and 50 cm/s.



**Figure 6** Sensitivity of the standard deviation of the velocity against error velocity threshold (solid line: mean value; dashed line: portion of valid samples)

Applying the average of the two horizontal standard deviations as error velocity threshold on our data resulted in over 70 % of valid samples for the vast majority of the depth cells, and did not significantly change the magnitudes of the velocities.

## 4 Conclusions

ADCP fixed-boat measurements have been carried out in the outflow region of a hydro power plant. The flow is characterized by highly turbulent flow and large quantities of air bubbles observed on the water surface. Despite of these flow conditions the ADCP classified over 97 % of the samples as valid for a vast majority of the depth cells.

The mean velocities were calculated based on the time-series collected for 10 minutes. The mean values reached a statistical stationary value in most of the depth cells. The calculated mean velocities showed a plausible distribution both along the verticals and in the cross-sections. The sensitivity of the mean velocities has also been examined against the error velocity threshold and it did not show significant changes with the used threshold.

The measurements provided the mean flow velocity field of the entrance region of the planned fish pass. The results can be used as validation data for the scale



model, so that the needed flow rate of the fish pass can be determined with a higher certainty. Further investigations are needed to determine if other discharges have significant effects on the flow field, and if field measurements are necessary for those cases.

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