Inflow Conditions at the Ashta HYDROMATRIX® - Powerhouse

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Abstract

Within the scope of planning the HYDROMATRIX®- power plant Ashta 1 in Albania different hydraulic question were posed by the consultant and the constructor. The following contribution treats questions concerning flow separation and vortex generation under different operational cases of the HYDROMATRIX®-turbine units. The given tasks were to be clarified and ensured by means of numerical calculations and hydraulic model tests. Therefore the Institute of Hydraulic Engineering and Water Resources Management of the Vienna University of Technology was commissioned by the Verbund International Company with the execution of a study. The results of the investigations, which were carried out to optimize the hydraulic design of the nearby powerhouse intake structure, are presented in this article.

1 Introduction

The „Energji Ashta Shpk“ from the Verbund International Company, a subsidiary of Austria´s largest electric utility Verbund, plans the world's largest HYDROMATRIX®- power plant as a Build-Operate-Transfer (BOT) project. The project company „Energji Ashta Shpk“ will build this power plant on the River Drin in northern Albania. The pre-civil work has already started in spring 2010, beginning of operation is scheduled for 2012.

1.1 Project Description

For the presented project, the HYDROMATRIX®-technology, advanced by Andritz Hydro, is used. Thereby small unregulated turbine-generator units, so called HYDROMATRIX®-turbines, are installed in front of a concrete structure. The dam construction further contains trash racks, skimming walls, draft tubes and other essential electro-mechanical equipment for operation. The turbine-generator units can be lifted in case of repair or revision and even can be removed during flood events. The use of the HYDROMATRIX®-technology should reduce construction and maintenance costs in comparison to the construction of a conventional power plant.

The total installed capacity of the power plant will finally be about 48 MW. It is designed as a low head diversion power plant with two stages, where the upper stage uses an existing downstream reservoir of a dam. The upper reservoir level will be raised by means of a rubber dam construction installed on top of an existing weir, the Spathara Weir (Figure 1-1).

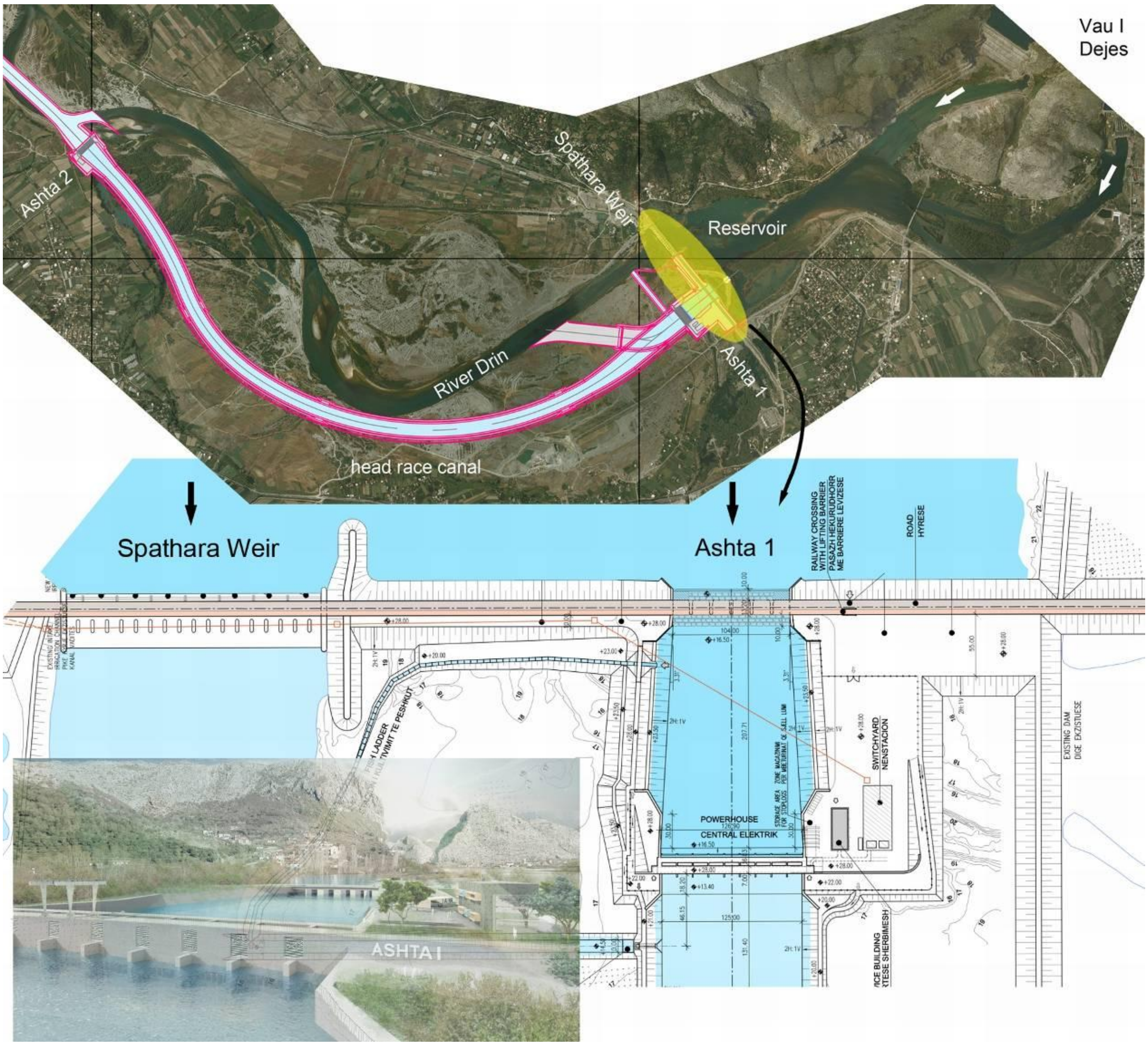


Figure 1-1. General overview of the HYDROMATRIX®-power plant Ashta and layout plan (source: PÖYRY Energy GmbH Austria)

The powerhouses of both stages have a width of 125 m each. They are separated into 9 powerhouse-blocks, each of them will be equipped with 5 HYDROMATRIX®-turbines with a maximum gross head of 5.4 m at Ashta 1. In case of maintenance or repair of the turbines the individual powerhouse-blocks can be sealed off from the forebay by stop logs. The design discharge of 560 m^3/s will be utilized in the upper stage by 45 HYDROMATRIX®-turbines. Downstream of the upper powerhouse an artificial diversion canal with a length of 5 km supplies the 45 HYDROMATRIX®-units of the powerhouse of the second stage. The outflow from the powerhouse of Ashta 2 will be returned to the Drin-river.

1.2 Objective of the Investigation

The primary aim of the investigation was the analysis and optimization of approaching flow conditions to the individual powerhouse-blocks and specifically to the individual HYDROMATRIX®-turbines under different operational cases of the turbine-units. To clarify these tasks, on the one hand a numerical calculation of the approaching flow conditions was carried out at the remote and also at the near field of the powerhouse intakes, and on the other hand a 3-D model of several powerhouse-blocks (PHB) was built.

2 Numerical Investigations

The numerical simulations had been carried out before the model tests, to predict the general flow situation and to get a first overview of the approaching flow to the turbines quickly which could also be used for a more effective planning of the hydraulic 3-D model.

The 3-D flow conditions next to the power house can be simulated in a 3-D model only. The 3-D simulations had been carried out on a simplified intake structure with a commercial CFD-code (Flow3d) with free water surface and about 3 million cells. The simulation was performed with an axial approaching flow towards the inlet section. The different turbine operational conditions for the simulations were previously defined in accordance with the turbine supplier Andritz Hydro as depicted in Figure 2-1.

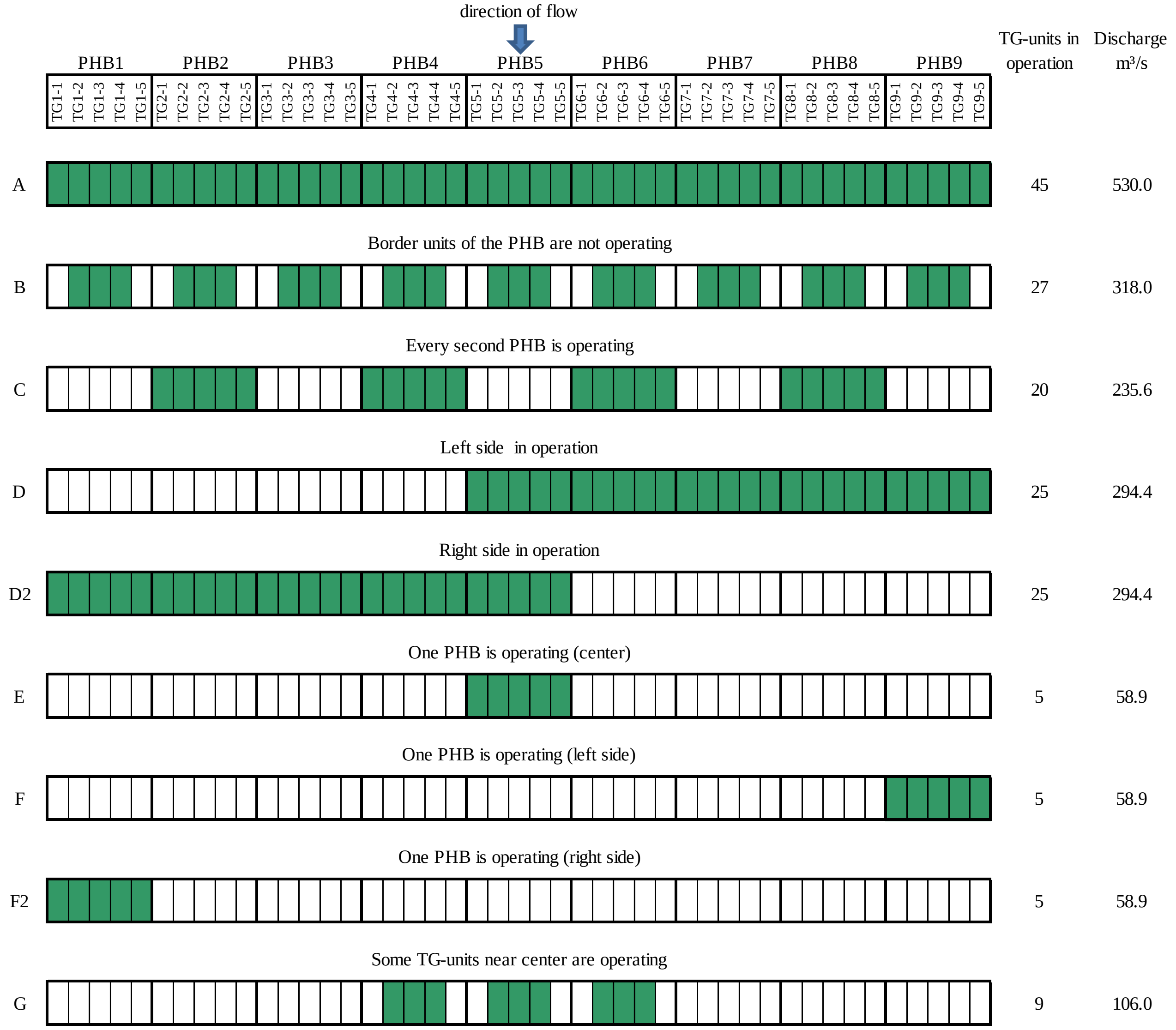


Figure 2-1. Simulated turbine operational conditions

2.1 Results of the 3D-Simulation of the Approaching Flow Conditions to the Turbines

The velocity field in a horizontal plane 3.5m above the bottom depicted below shows a comparatively evenly-distributed flow profile for case A.

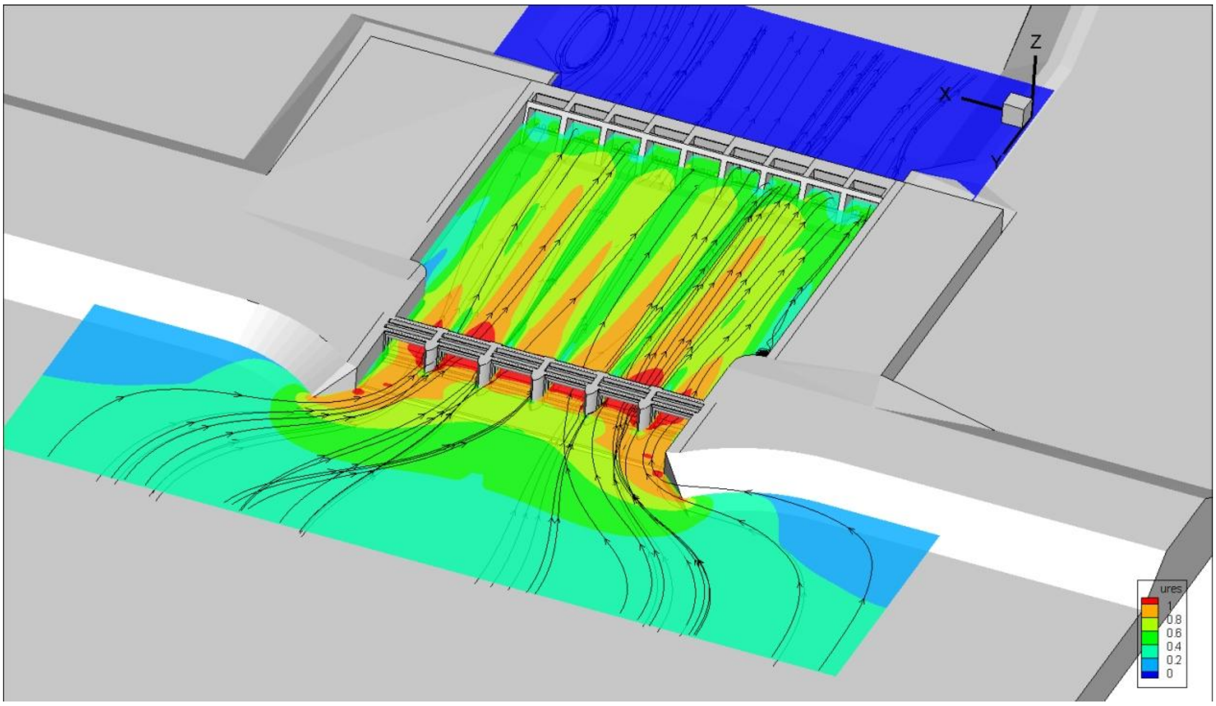


Figure 2-2. Streamlines and velocity contours for operational case A

Also in operational case C flow through the turbines was evenly distributed. The pictures below show the velocity contours in a vertical plane approx. 4m in front of the turbines for case C and, in comparison to this, for case D. Here, velocities in the middle section are somewhat higher than the mean values, whereas in the left field slightly lower (deviations from mean velocity max. 4%).

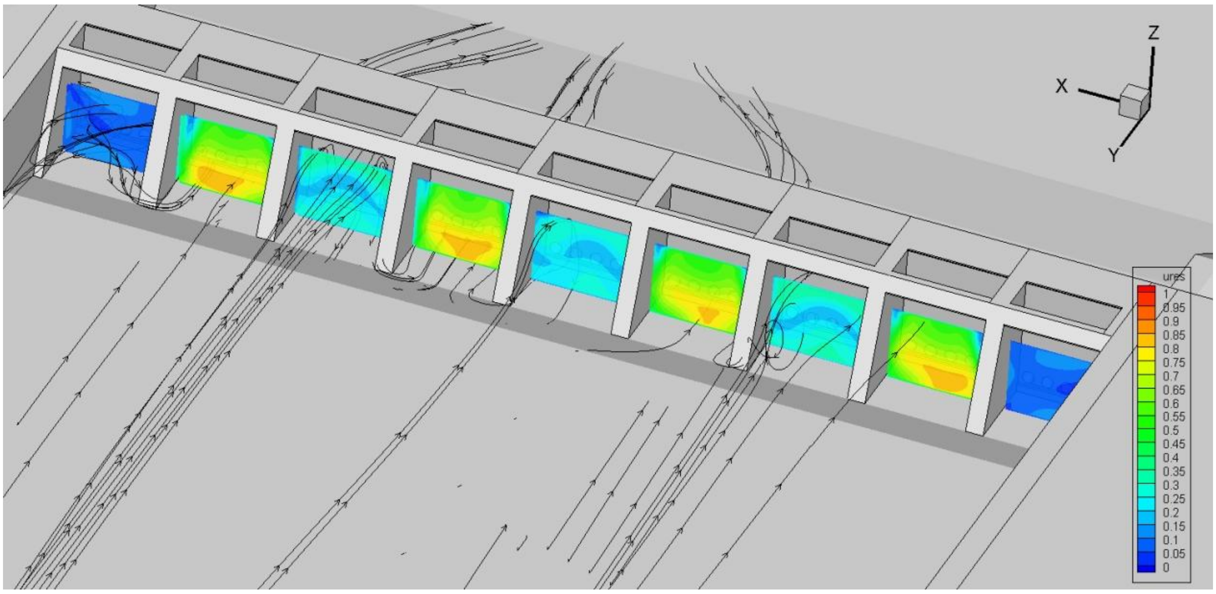


Figure 2-3. Streamlines and velocity contours for operational case C

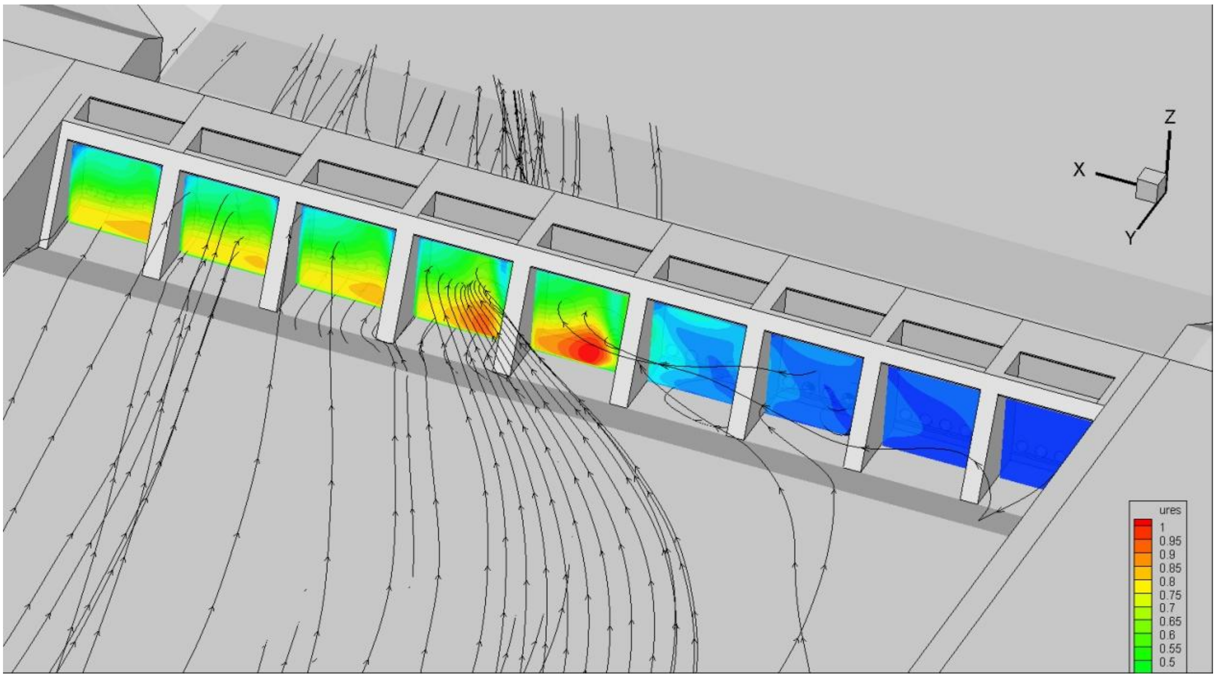


Figure 2-4. Streamlines and velocity contours for operational case D

Even in case F all 5 turbines in the outer left section flow was fairly well distributed. The simulations also showed the tendency for a surface vortex development.

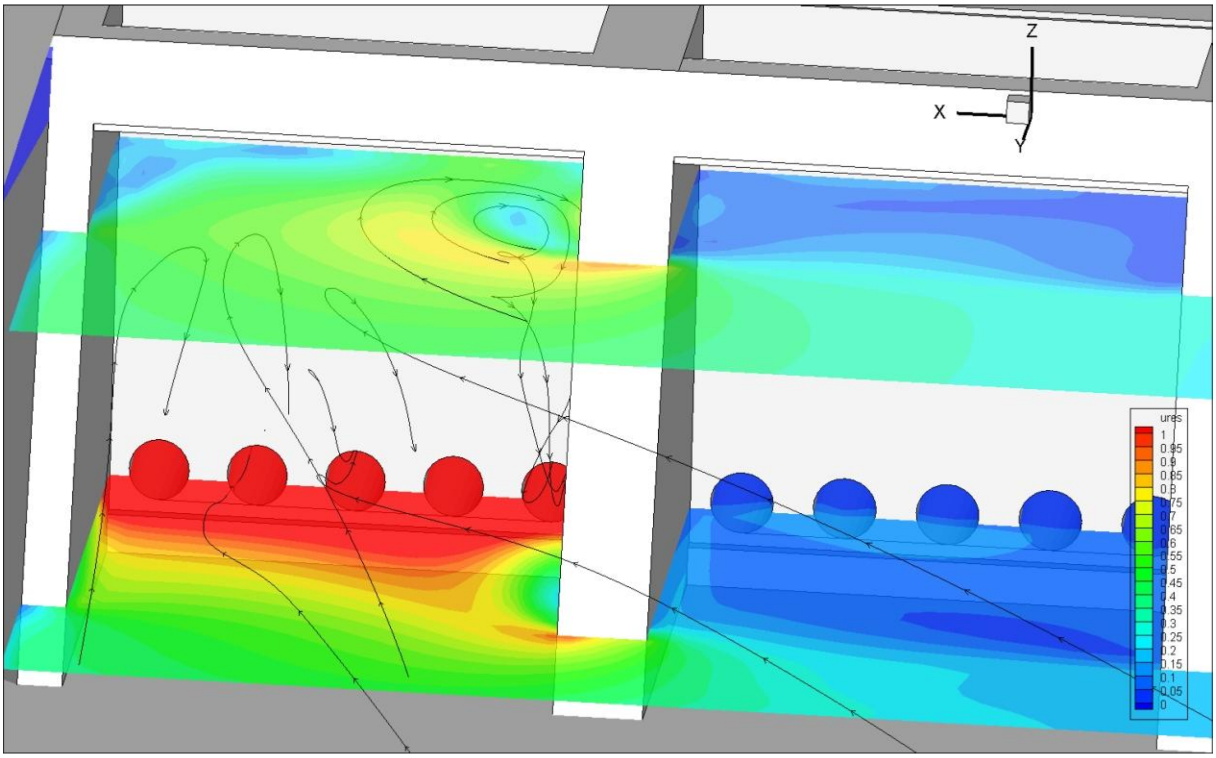


Figure 2-5. Streamlines and velocity contours for operational case F

Resulting from the combination of the simulations for the different turbine operation conditions as depicted before, the following conclusions can be drawn for the situation at the prototype:

- For operating conditions A and B the simulations showed that all operating TG-units had equal flow.
- In configuration C flow through the outer left TG-units was slightly worse than through the middle ones.

- In configuration D and D2 flow was less even in the outer turbines (TG5-1 and TG5-2 for case D and TG5-4 and TG5-5 for case D2) than the others.
- In configuration E the 2 TG-units on the sides (TG5-1 and TG5-5) were impinged on worse than the inner ones.
- For the right tg-unit in case F (TG9-5) and the left unit in case F2 (TG1-1) flow was comparatively badly distributed.

3 Experimental Investigation

By means of hydraulic experiments a smooth and low-loss intake flow should be able to be achieved by an adequate design of the entire intake structure (skimming wall, separation pier etc.).

3.1 Setup of the Hydraulic model

The hydraulic 3-D model was operated according to Froude's law of similarity. For economic reasons only a sub-domain of the entire power plant was built in a hydraulic 3-D model to a scale of 1 : 13.2 (Figure 3-1). This specific model part consisted of a central powerhouse-block with 5 HYDROMATRIX®-units made of plexiglass where the inflow conditions could be visually observed. Adjacent on both sides 2 simplified additional powerhouse-blocks were built to simulate different operational flow cases at the powerhouse-blocks. By the installation of a side wall (dividing wall) in front of a pier of the central powerhouse-block, this block could operate as a border powerhouse-block as well. The entire model setup had a width of 7 m, an upstream length of 8 m, a height of 1.5 m and a water depth of approximately 1 m (Figure 3-2).

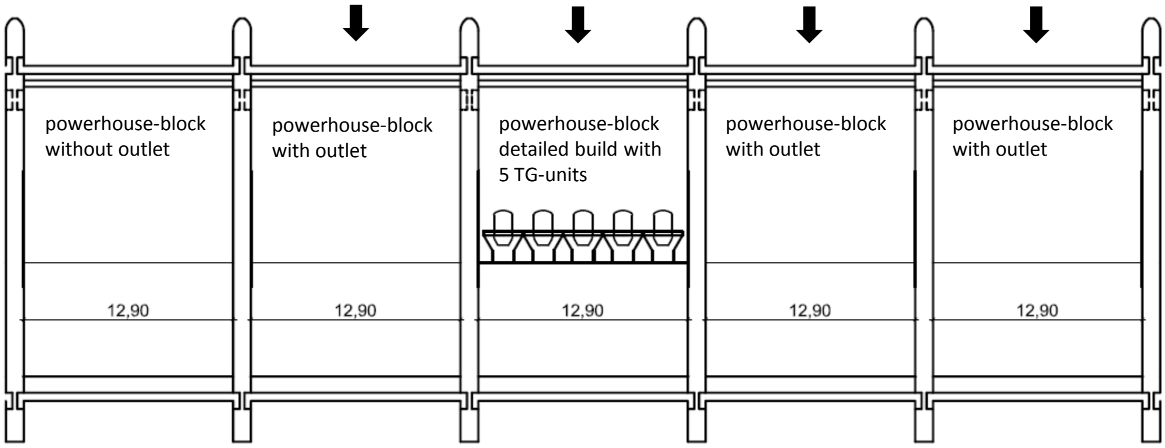


Figure 3-1. Set up of the hydraulic model

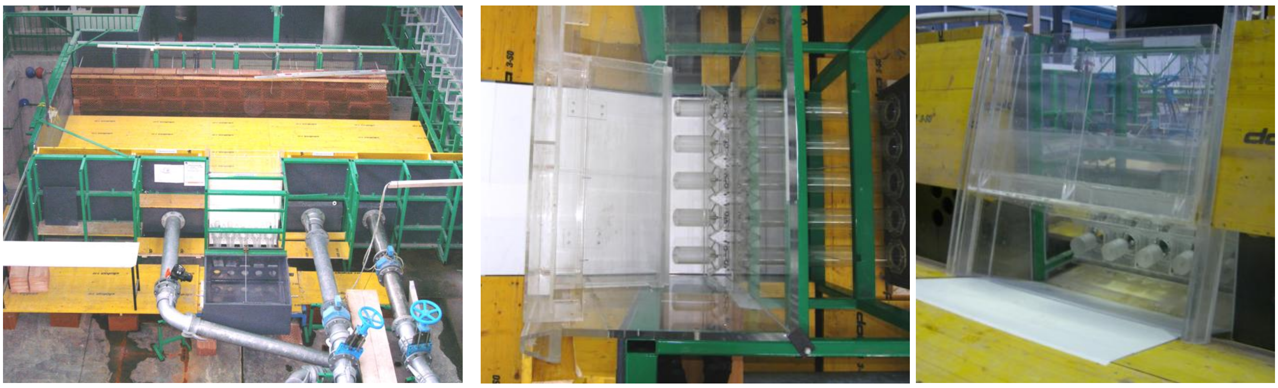


Figure 3-2. Downstream-, top- and upstream-view of the model setup

3.2 Execution of the Model Tests - Testing Routine

For the assessment of the approaching flow conditions to the HYDROMATRIX®-turbines located in an inner powerhouse-block (PHB), 5 operational cases were defined as decisive (Figure 3-3). The selection based on operational demands, e.g. that a practicable systematic control for the operation of the turbines is possible, but it also serves for the evaluation of extraordinary operational cases where the powerhouse-blocks or turbine units are operating apart from each other.

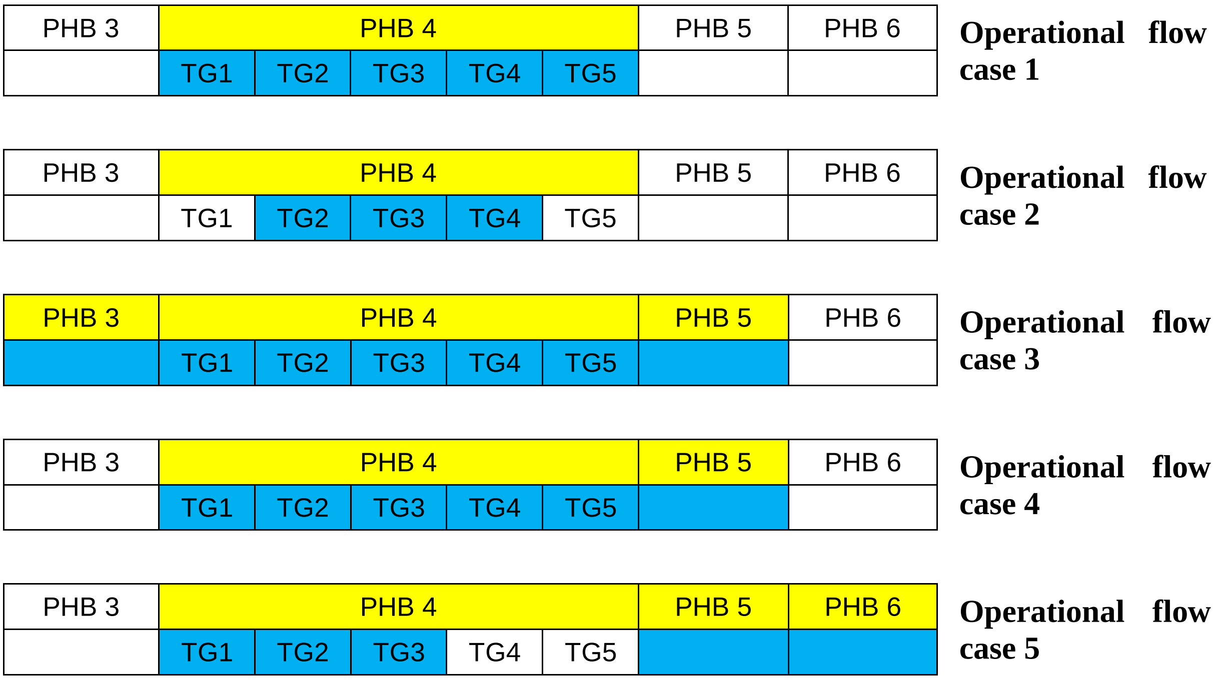


Figure 3-3. Operational flow cases for an inner powerhouse-block

The approaching flow conditions at a boundary powerhouse-block PHB 1 (mirrored PHB 9) were investigated using the following 3 significant operational cases as well (Figure 3-4). The selection of these flow cases was based on hydraulic pre-tests where a random generation of detrimental vortices in the vicinity of the border piers could be clearly identified.

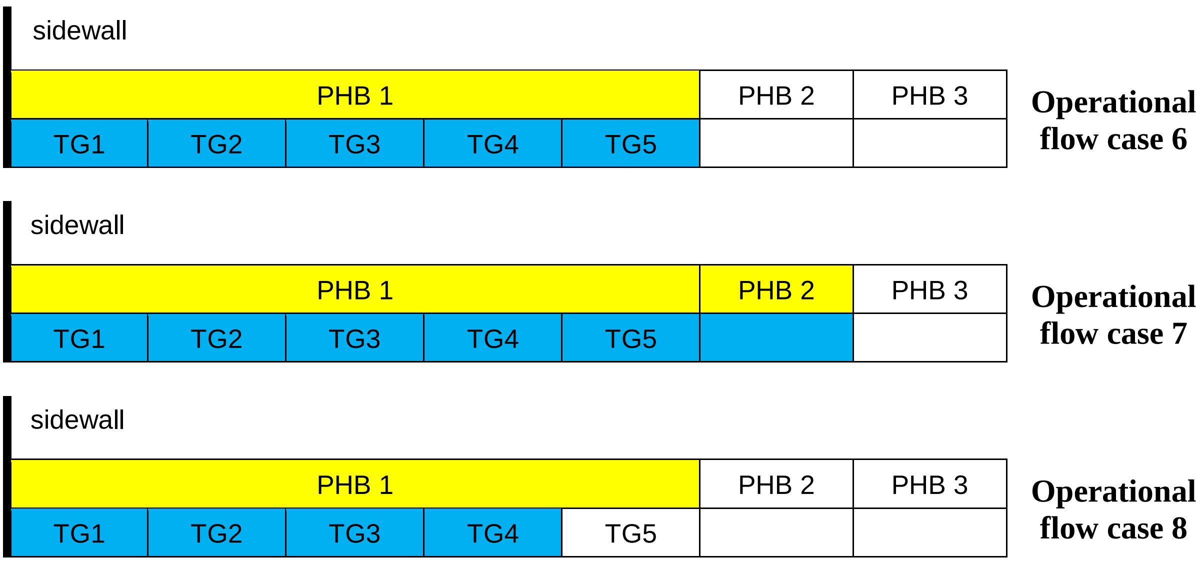
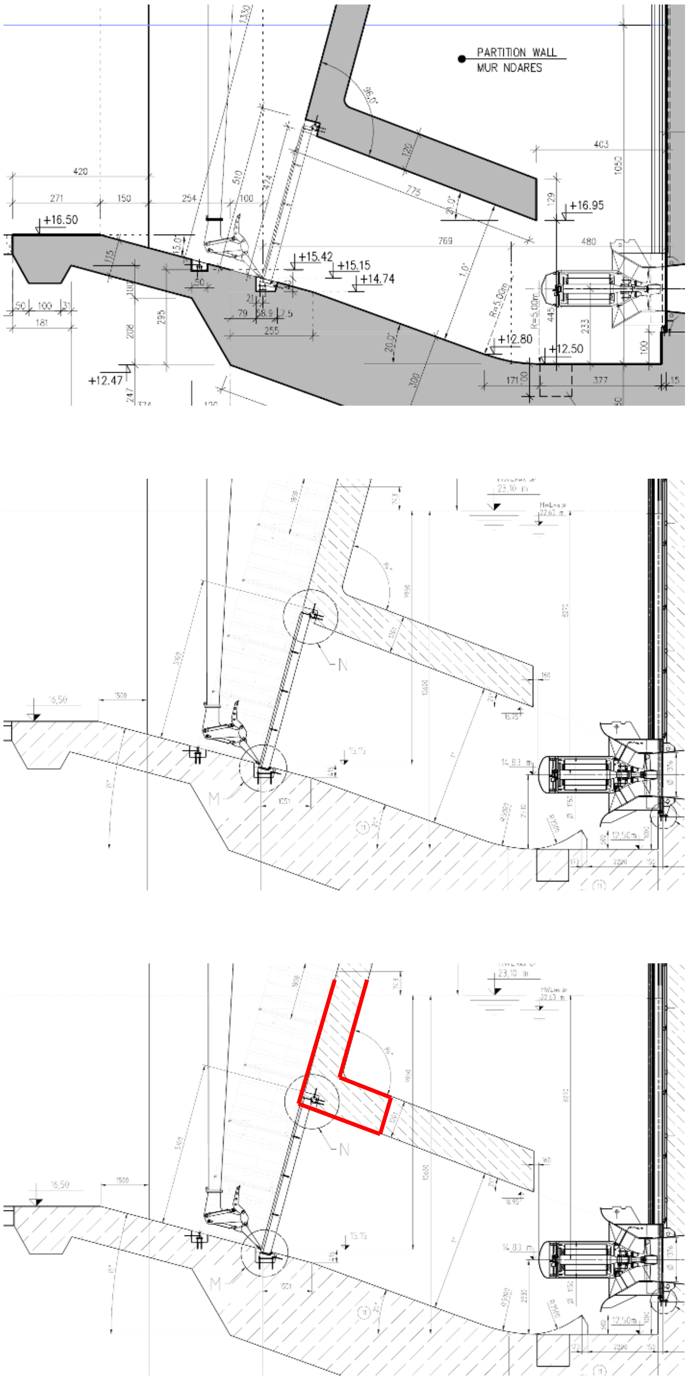


Figure 3-4. Operational flow cases for a boundary powerhouse-block

3.3 Optimization of the Intake Geometry

The experimental tests to improve the approaching flow conditions comprised the investigation of 3 variants of the intake design of a powerhouse-block (Figure 3-5) under the above mentioned significant turbine operational cases in accordance with the client Verbund International and the turbine supplier Andritz Hydro.



Variant 1

- Extended skimming wall elbow
- Straight intake ramp

Variant 2

- Extended skimming wall elbow
- Bottom deflector at the end of the intake ramp

Variant 3

- Cropped skimming wall elbow
- Bottom deflector at the end of the intake ramp

Figure 3-5. Different intake designs of the powerhouse (source: Andritz Hydro)

Variant 1 shows at the upstream edge of the skimming wall (trash rack support) a marginal continuous flow separation zone which produces a small hydraulic loss also on the turbine inflow head. Due to constructive reasons (limited trash rack supporting beam length) a redesign of the hydraulic shape of this relatively sharp edge is not expedient. This design requirement is also valid for the other Variants 2 and 3.

Towards this flow separation zone the long inclined skimming wall arm enforces a controlled guidance of the turbine flow and prevents a massive development of a shear zone between the wake zone behind the skimming wall and the main stream to the turbines. However, the inflow to the turbines does not take place without hydraulic losses, because the bottom near fluid layer passes through below the intake cones of the turbines and dissipates in the dead water behind it. The flow around the flattened generator bulb head shows almost no separation and probably generates only small head-losses. (Figure 3-6)

Figure 3-6. Variant 1, bottom near flow, flow around generator bulb and flow field after skimming wall

The test findings of Variant 1, where the bottom near flow passes the turbine intakes beneath, led to the installation of a bottom deflector, which significantly improved the proximate inflow to the turbines.

Due to these refinements of flow guidance at the ceiling and at the bottom, the main stream (confined by both boundary layers) can be totally drawn into the turbines (Figure 3-7).

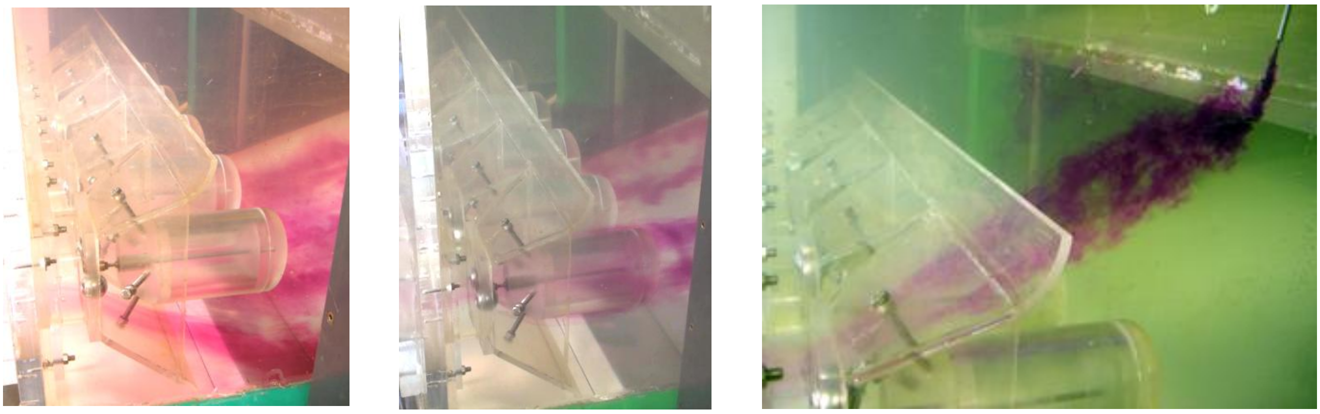


Figure 3-7. Variant 2, bottom near flow, flow around generator bulb and flow field after skimming wall

To reduce the construction costs of the skimming wall, Variant 2 was compared with an additional Variant 3 with a cropped skimming wall elbow to evaluate the hydraulic effects.

Due to the reduced flow guidance at the ceiling Variant 3 developed a distinct shear zone with high turbulence production accompanied with shock losses (in all investigated operational flow cases), which consequently led to unfavorable turbine inflow conditions. In the operational flow case 5 a massive air entraining surface vortex occurred in the right corner behind the skimming wall. Nevertheless the bottom near flow was not affected by this measure and was directed into the turbine intakes by the deflector undisturbed.

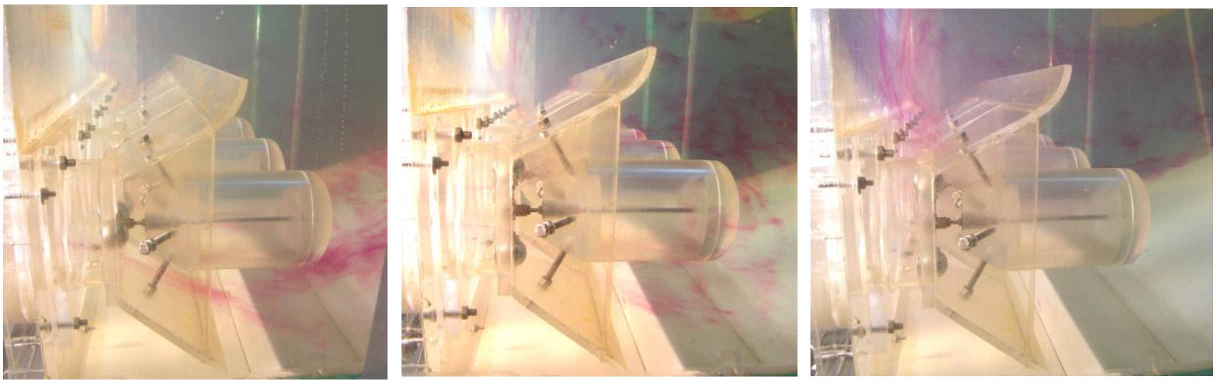


Figure 3-8. Variant 3, bottom near flow, flow around generator bulb and flow at the upper zone of the turbines

The cropped skimming wall elbow of Variant 3 will cause a head loss of approximately 10 cm at the prototype (in the model about 6 – 8 mm) in comparison to Variant 2 (design proposal). This additional head loss of about 1.7 % of the gross head occurs in the case of one fully operating powerhouse-block with 5 turbine-units (discharge 5 x 12.5 = 62.5 m^3/s) under design conditions.

3.4 Identification of Surface Vortices

Vortex generation in a hydraulic model can be generally revealed by increasing the flow rate (Froude scaling). In the presented study it was not necessary to increase the design discharge above the design level of the turbines to amplify the occurrence of swirl phenomena, because different surface vortices were already induced in front of the skimming wall of the powerhouse intake at that flow. The intensity of vortices can be classified according to Figure 3-9.

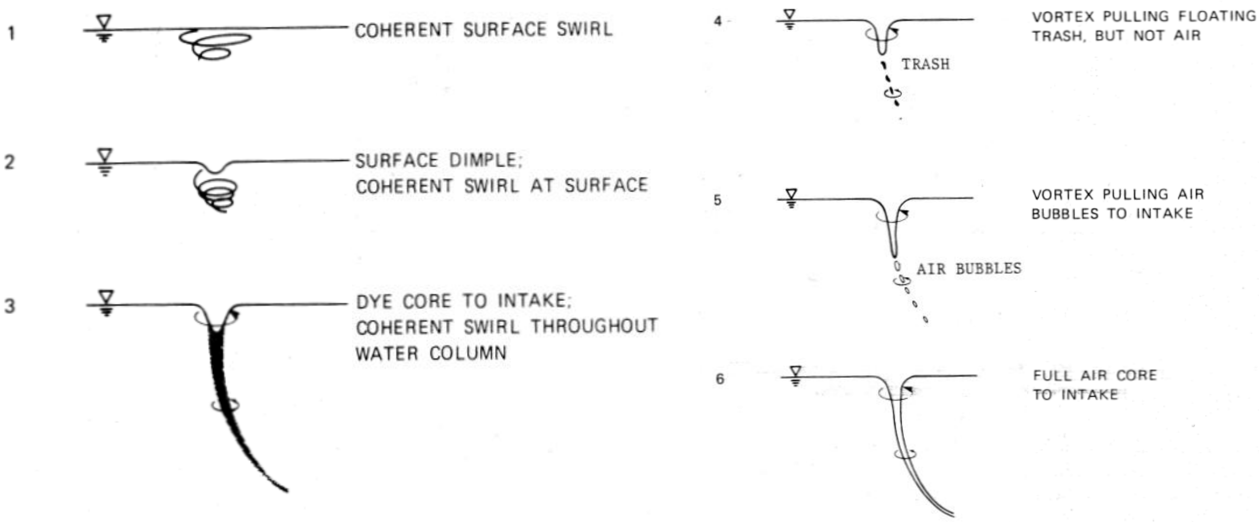


Figure 3-9. Vortex classification according to Alden Research Laboratory ARL, source: [1]

Generally surface vortices of class 2 (coherent swirl generation at surface with dimples) up to class 4 (stronger vortices which pulled floating trash downwards into the vortex core) occurred at all investigated operational flow cases. Nevertheless, intensive vortex generation with air entrainment (vortex class 5 and 6) could not be observed in any of the investigated operational flow cases.

Figure 3-10 to Figure 3-12 show some examples of randomly occurring surface vortices in front of the skimming wall, which were made visible by means of dye injection. They are developing randomly at a distance of 0.5 up to 3 m along the upstream side of the skimming wall within a certain magnitude range (vortex class 1 up to 4).

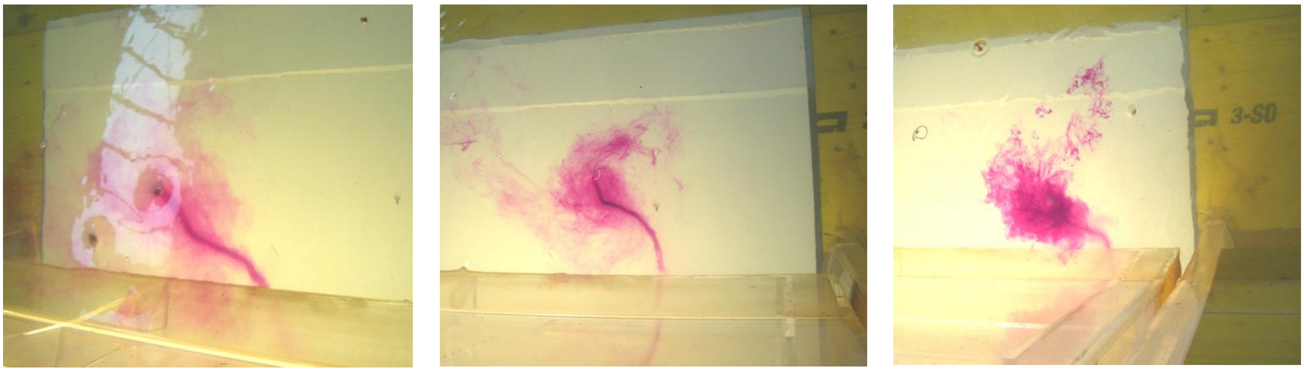


Figure 3-10. Flow case 1, vortex swirl in front of the skimming wall

An intensive vortex generation in front of the separation piers heads can be observed when powerhouse-blocks are operating in parallel. (Figure 3-11)

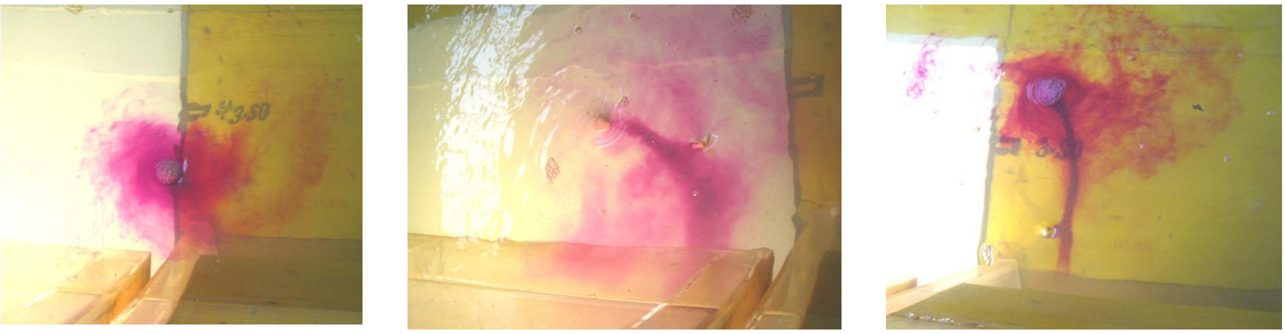


Figure 3-11. Flow case 3, vortex formation in front of a separation pier

During the operation of the border powerhouse-blocks a boosted surface vortex generation could occur in the vicinity of the upstream side walls as well.

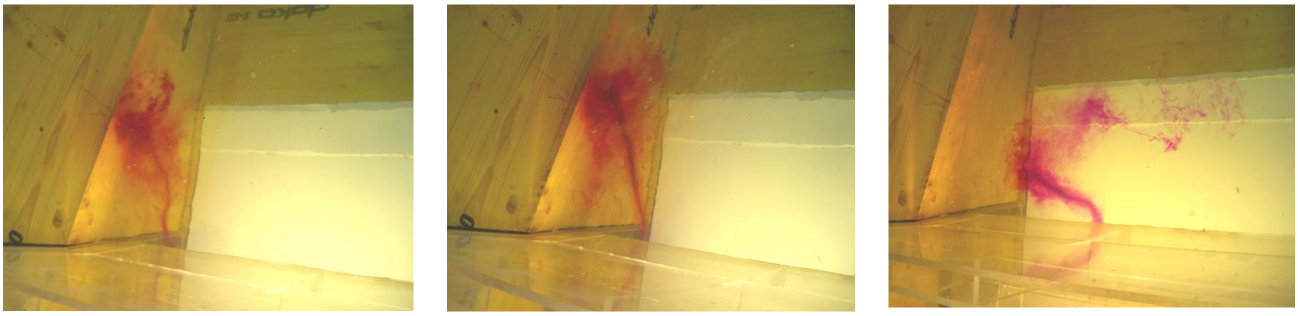


Figure 3-12. Flow case 6, vortex formation in front of the skimming wall at a border powerhouse-block

If these swirl formations at the intake are stronger than expected and have negative influences on the turbine operation of the prototype, a control of vortex generation should be installed in form of floating devices (grates, booms etc.). These measures should disturb a distinct circulation development in front of the skimming wall.

4 Concluding Remarks

The investigations of the approaching flow conditions to the turbines of the HYDROMATRIX®-powerhouse Ashta 1 were carried out numerically and on a hydraulic sub-model with a scale of 1 : 13.2. The following important findings were obtained:

- In general the numerical results conform fairly well to the test results, despite simplified assumptions.
- For hydraulic reasons Variant 2 with an extended skimming wall elbow and a deflector on the bottom will be suggested as design proposal. In contrast to Variant 3, which has a cropped skim-

ming wall elbow and a bottom deflector, the intake head losses can be reduced to about 8 to 10 cm in the prototype. This corresponds to 1.7 % of the gross head of the upper stage.

- When the powerhouse-blocks were operated separately, e.g. PHB 1, PHB 3 and PHB5 in operation, the tests showed higher losses due to a higher flow contraction at the separation piers.
- Highly swirling approaching flow conditions at the turbine intakes have not been observed for the operational flow cases examined.
- In contrast, vortices of classes 2 to 4 have been observed under the given circumstances at the model close to the skimming wall. However, there was no air entrainment into the turbine-units in all tests at any time, but nevertheless there remains a certain minimum risk in the prototype. In such an extraordinary case the installation of some constructive provisions for vortex suppression in front of the skimming wall are proposed. This could be for instance swimming floating barriers or wooden swimming grillages which prevent a stronger random vortex formation with air entrainment.
- A certain transport of fine bed load and suspended load could lead to aggradation in the forebay of the powerhouse-blocks and in the turbines themselves. Care should be taken to excavate those areas if needed.
- In matters of low – loss turbine operation and uniformly distributed operational times of the turbines there should not be more than two separated groups of turbine–units in operation to minimize contraction effects.

Despite great progress in CFD-calculation, hydraulic model tests are presently an indispensable tool for the assessment of complex hydro-mechanical tasks. This article presents an example of a combination of hydraulic experiment and numerical simulation, in which the advantages of both methods were utilized for an optimized design of a hydraulic structure.

References

[1] Jost Knauss (editor), “Swirling Flow Problems at Intakes”, A.A.Balkema, Rotterdam, 1987