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ORIGINAL RESEARCH  
PAPER



# Analyzing the impact of intake structure on the flow at low pressure SHPP

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## ABSTRACT

The structural parts of intake structures directly affect the flow velocity distribution in the turbine intake of small hydropower plants, where inhomogeneous flow leads to uneven load of the turbine units causing operational problems. A 2D numerical flow modeling was used for investigations of the flow in an intake structure of a low-head small hydropower plant. The effects of shape changes of the intake structure on the flow velocity distribution in the turbine intakes were investigated and assessed proving significant effect of the shapes of the intake structure on the flow homogeneity in turbine intakes.

## KEYWORDS

hydropower, small hydropower plant, intake structure, numerical modeling, flow homogeneity

## 1. INTRODUCTION

One of the most important parts of Small HydroPower Plants (SHPPs) are the intakes, that directly relate to the entire power plant function. Many authors dealt with the flow in the intake structures [1]. The intakes are connected to a storage reservoir and take water to the power plant. A hydraulically appropriate design of the inlets is linked to achieving the required hydropower parameters. Proper design of the intake ensures sufficient water flow and should provide minimal pressure losses [2, 3]. Non-uniform influx causes irregular load on the turbine runner producing additional radial forces acting on the rotor [4]. The correct construction of the intake structure also prevents the formation of vortices in this area [5–7].

A great influence on the flow quality has the homogeneity of the flow velocity field at the turbine intake. An inhomogeneous flow velocity field causes negative effects to the turbine performance, decreasing of its efficiency and it causes uneven mechanical load to turbine unit parts resulting in decreasing of its lifetime. Due to reduction of the costs of the project, the shapes of intake structures of SHPP with bulb turbines are often not correctly hydraulically designed. This fact results in operational problems of SHPP [8].

Flow in intakes can be solved by physical models, 2D or 3D modeling. Developing measurement capabilities have allowed the emergence of objective criteria that evaluate the interaction between objects of hydropower plant and turbine. The methodology of flow under low pressure SHPP is based on the starting points of the authors Fisher and Franke [9]. Their issues related to flow conditions are mostly dealing with low pressure hydropower plants with bulb turbines. This method is significantly applied to the results of numerical models.

Numerical models are used to solve flow problems in open channels [10], groundwater flow [11] and also sediment transport [12]. The paper describes the evaluation of flow in the intake of a low pressure SHPP. To assess the flow, a 2D numerical model of flow was created, which should prove the suitability and possible problems of intake structures and their construction solutions using 2D modeling tools.

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## 2. MATERIALS AND METHODS

The object of analysis of the suitability of intake structure design for homogeneous flow conditions was the Stará L'ubovňa SHPP, a small hydropower plant with bulb turbines. The SHPP is located near Stará L'ubovňa on the Poprad River. The project consists of a weir (2 weir fields with control flaps), a low-head small hydropower plant with bulb turbines and a fish pass. The small hydropower plant and weir control system maintains operating water level at 520.54 m for which the gates are designed. The control is carried out by the left field of the weir, through which a flow of up to  $150 \text{ m}^3 \text{ s}^{-1}$  can be released. When larger flow rates occur, both weirs' fields are used [13].

The power house and structures of the SHPP are located on the left bank of the river. The design flow of the SHPP is  $18.2 \text{ m}^3 \text{ s}^{-1}$  and the design head is 3.16 m. The turbines have a diameter of 1,290 mm and a maximum power is 510 kW for the design flow [13] (Fig. 1).

The 2D numerical model of flow of the SHPP Stará L'ubovňa was created in the River2D program. River2D is free software, 2D model solve the basic mass conservation equation and two (horizontal) components of momentum conservation [14].

The model geometry was created from the altitude data of the SHPP. The bed of the stream was considered at a uniform level, the intake structure of the SHPP was modeled to the real situation. The model used Manning's roughness coefficient of 0.025, which describes a straight regular gravel bottom trough [2].

The inlet boundary condition (upstream boundary condition) was determined by the flow that flows into the modeled area. The outflow boundary condition (downstream boundary condition) was determined by the water level elevation (Fig. 2).

In the simulations, the boundary conditions were changed to approximate the various variants of the hydropower plant operation. The upstream boundary condition is



Fig. 1. The small hydropower plant Stará L'ubovňa  
(Source: Dušička)

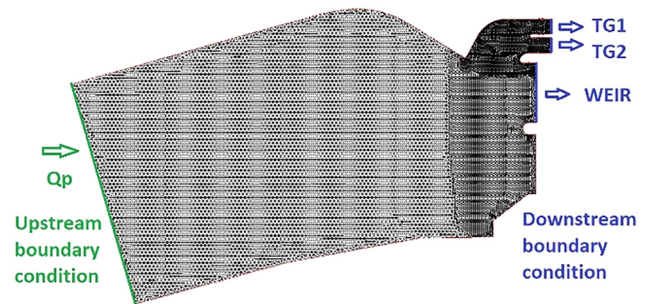


Fig. 2. Modeling mesh and boundary condition

tagged  $Q_p$  and the flow rates of  $18.2$  and  $32.7 \text{ m}^3 \text{ s}^{-1}$  were used in the calculations. The downstream boundary condition determines the operating level of 520.54 m, which was changed, based on the selected scenario. The downstream boundary condition was determined by the bulb turbine TG1, the bulb turbine TG2 and the left flap of weir called WEIR. Overall 8 different operational scenarios have been simulated (Table 1).

The simulation results were evaluated in turbine intake profiles (profile of screenings), where the distribution of flow velocities was evaluated. The flow velocities in this profile were compared with the average flow velocity in the turbine intake profile. The comparison is expressed by the percentage relative deviation of flow rates from the average flow velocity.

For assessments, flow rates of  $18.2$  and  $32.7 \text{ m}^3 \text{ s}^{-1}$  were selected. A flow  $18.2 \text{ m}^3 \text{ s}^{-1}$  represents the design discharge of the SHPP. One turbine unit should be able to process a flow  $9.1 \text{ m}^3 \text{ s}^{-1}$ . A flow  $32.7 \text{ m}^3 \text{ s}^{-1}$  represent 30-day flow. The operating level 520.54 m was determined by the operational manual. The operating level tolerance is  $\pm 80 \text{ mm}$  [13].

In order to optimize the velocity distribution in the intake structure, two modifications of the inlet shapes have been designed (Fig. 3). Current state simulations have shown an improper connection of the inlet structure to the river bed. The left wall of the inlet is connected to the river bed at an angle of approximately  $60^\circ$ , which causes the current to tear from the walls, creation of “flow shadows” and creation of vortices. These negative effects need to be eliminated to help improve the flow velocity distribution.

In the first modification, the original inlet structure was preserved. The modification consists in shifting the riverbank to the level of submerged screen and rounding the wall edges, while the length of submerged screen remained unchanged.

Modification 2 represents more radical changes in the structural part of the inlet. The submerged screen was extended by 5 m, the wall edges were rounded and the riverbank was connected smoothly to the intake. The construction of the left wall of the inlet was modified and connected to the river bed at an angle of  $30^\circ$ .

The flow geometry and modeling mesh were created to edit the intake structure. The simulations were calculated for the upstream boundary condition flow rate  $Q_p = 18.2$  and



Table 1. An overview of simulated scenarios with their boundary conditions

Scenario	Upstream boundary condition ( $\text{m}^3 \text{s}^{-1}$ )	Downstream boundary condition (m)			Flow ( $\text{m}^3 \text{s}^{-1}$ )		
	$Q_P$	TG1	TG2	WEIR	TG1	TG2	WEIR
A	18.2	520.54	520.54	–	10.7	7.5	–
B	18.2	520.54	520.524	–	9.1	9.1	–
C	32.7	520.54	–	520.54	4.3	–	28.4
D	32.7	520.54	–	520.566	9.1	–	23.6
E	32.7	–	520.54	520.54	–	6.4	26.3
F	32.7	–	520.54	520.557	–	9.1	23.6
G	32.7	520.54	520.54	520.54	4.7	5.3	22.7
H	32.7	520.549	520.54	520.574	9.1	9.1	14.5

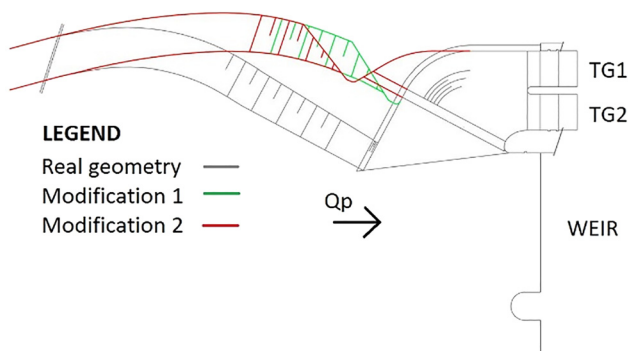


Fig. 3. Designs of modifications of the intake shapes

$32.7 \text{ m}^3 \text{s}^{-1}$ . The downstream boundary condition varied depending on the modeled scenarios. An overview of the simulated scenarios of modifications is given in Tables 2 and 3.

### 3. RESULTS AND DISCUSSION

Eight scenarios for real geometry were simulated. In the scenarios A, C, E, G the initial model calculations were performed. Based on the flow distribution, the operating levels were adjusted until the flow distribution was even for turbines with a maximum flow rate of  $9.1 \text{ m}^3 \text{s}^{-1}$ . The scenarios B, D, F, and H represent the resulting distribution of flow. The scenarios B and H have been selected and the resulting flow velocity maps are shown in Figs 4 and 5.

#### 3.1. Real geometry – Scenario B

Boundary conditions are:  $Q_P = 18.2 \text{ m}^3 \text{s}^{-1}$  (total inflow);  $TG1 = 520.54 \text{ m}$ ;  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level, outflow);  $TG2 = 520.524 \text{ m}$ ;  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level, outflow) (Fig. 4).

#### 3.2. Real geometry – Scenario H

Boundary conditions are:  $Q_P = 32.7 \text{ m}^3 \text{s}^{-1}$  (total inflow);  $TG1 = 520.549 \text{ m}$ ,  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level, outflow);  $TG2 = 520.54 \text{ m}$ ,  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level, outflow);  $WEIR = 520.574 \text{ m}$ ,  $14.5 \text{ m}^3 \text{s}^{-1}$  (water level, outflow) (Fig. 5).

In order to improve the flow parameters, two modifications of the inlet shapes have been designed. For each modification, 8 simulations were also created. Adjustment simulations consisted of operating level changes for selected flow rates. Simulations A, C, E, and G represent the initial calculations; simulations B, D, F, and H represent the final calculations. Figs 6–9 shows the resulting flow velocity maps for scenarios B and H.

#### 3.3. Modification 1 – Scenario B

Boundary conditions are:  $Q_P = 18.2 \text{ m}^3 \text{s}^{-1}$  (total inflow);  $TG1 = 520.54 \text{ m}$ ,  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level, outflow);  $TG2 = 520.528 \text{ m}$ ,  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level, outflow) (Fig. 6).

#### 3.4. Modification 1 – Scenario H

Boundary conditions are:  $Q_P = 32.7 \text{ m}^3 \text{s}^{-1}$  (total inflow);  $TG1 = 520.543 \text{ m}$ ,  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level; outflow);  $TG2 = 520.54 \text{ m}$ ,  $9.1 \text{ m}^3 \text{s}^{-1}$  (water level; outflow);  $WEIR = 520.57 \text{ m}$ ,  $14.5 \text{ m}^3 \text{s}^{-1}$  (water level; outflow) (Fig. 7).

Table 2. Modification 1 – simulated scenarios with their boundary conditions

Scenario	Upstream boundary condition ( $\text{m}^3 \text{s}^{-1}$ )	Downstream boundary condition (m)			Flow ( $\text{m}^3 \text{s}^{-1}$ )		
	$Q_P$	TG1	TG2	WEIR	TG1	TG2	WEIR
A	18.2	520.54	520.54	–	10.1	8.1	–
B	18.2	520.54	520.528	–	9.1	9.1	–
C	32.7	520.54	–	520.54	5.0	–	27.7
D	32.7	520.54	–	520.566	9.1	–	23.6
E	32.7	–	520.54	520.54	–	6.7	26.0
F	32.7	–	520.54	520.555	–	9.1	23.6
G	32.7	520.54	520.54	520.54	4.7	5.8	22.2
H	32.7	520.543	520.54	520.57	9.1	9.1	14.5



Table 3. Modification 2 – simulated scenarios with their boundary conditions

Scenario	Upstream boundary condition ( $\text{m}^3 \text{s}^{-1}$ )	Downstream boundary condition (m)			Flow ( $\text{m}^3 \text{s}^{-1}$ )		
	$Q_P$	TG1	TG2	WEIR	TG1	TG2	WEIR
A	18.2	520.54	520.54	–	9.8	8.4	–
B	18.2	520.54	520.529	–	9.1	9.1	–
C	32.7	520.54	–	520.54	6.3	–	26.4
D	32.7	520.54	–	520.56	9.1	–	23.6
E	32.7	–	520.54	520.54	–	6.9	25.8
F	32.7	–	520.54	520.555	–	9.1	23.6
G	32.7	520.54	520.54	520.54	5.7	5.9	21.1
H	32.7	520.543	520.54	520.564	9.1	9.1	14.5

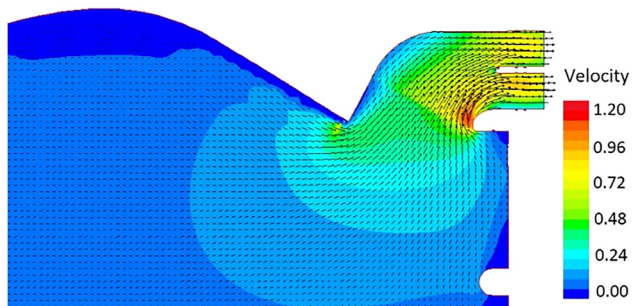


Fig. 4. Real geometry – Scenario B – Distribution of flow with vectors

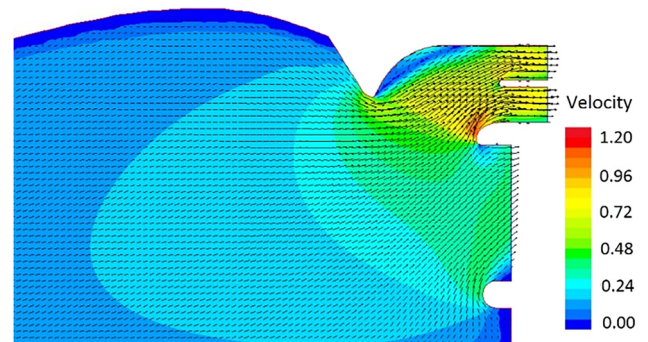


Fig. 7. Modification 1 – Scenario H – Distribution of flow with vectors

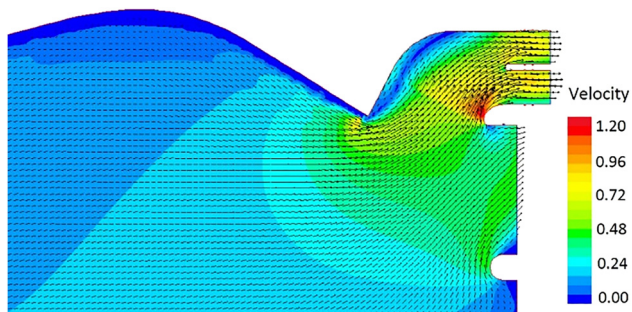


Fig. 5. Real geometry – Scenario H – Distribution of flow with vectors

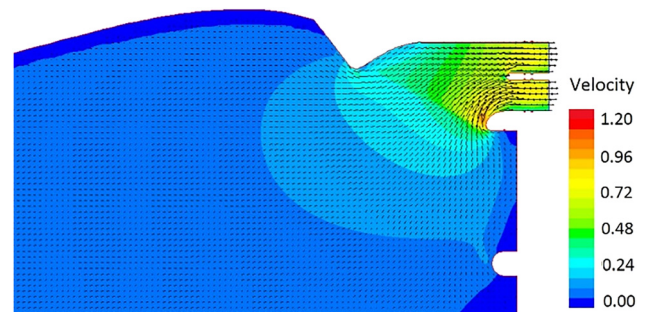


Fig. 8. Modification 2 – Scenario B – Distribution of flow with vectors

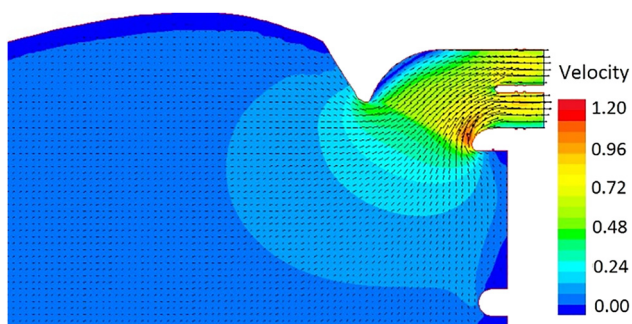


Fig. 6. Modification 1 – Scenario B – Distribution of flow with vectors

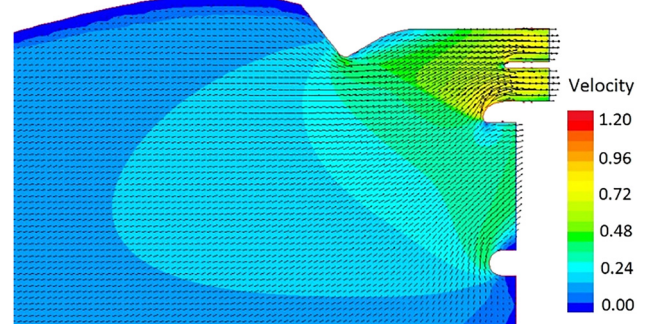


Fig. 9. Modification 2 – Scenario H – Distribution of flow with vectors



### 3.5. Modification 2 – scenario B

Boundary conditions are:  $Q_p = 18.2 \text{ m}^3 \text{ s}^{-1}$  (total inflow);  $TG1 = 520.54 \text{ m}$ ,  $9.1 \text{ m}^3 \text{ s}^{-1}$  (water level; outflow);  $TG2 = 520.529 \text{ m}$ ,  $9.1 \text{ m}^3 \text{ s}^{-1}$  (water level; outflow) (Fig. 8).

### 3.6. Modification 2 – Scenario H

Boundary conditions are:  $Q_p = 32.7 \text{ m}^3 \text{ s}^{-1}$  (total inflow);  $TG1 = 520.543 \text{ m}$ ,  $9.1 \text{ m}^3 \text{ s}^{-1}$  (water level; outflow);  $TG2 = 520.54 \text{ m}$ ,  $9.1 \text{ m}^3 \text{ s}^{-1}$  (water level; outflow),  $WEIR = 520.564 \text{ m}$ ,  $14.5 \text{ m}^3 \text{ s}^{-1}$  (water level; outflow) (Fig. 9).

For real geometry uneven distribution of the velocity fields in the intake structure is obvious. The shape of the intake structure affect the flow in a way that in a certain section of the inlet a flow with opposing direction as required occurs. Flow simulations in the profile of screenings produced higher velocities in the left part of the flow profile. The flow velocities in the right section dropped sharply. The relative deviations of flow velocity vary from approximately +25% to –50% for both flow rates, which proves great inhomogeneity of the flow conditions in this area (Figs 10 and 11).

Modification 1 and modification 2 are compared with the real geometry of the intake structure. In modification 1, the relative deviations of flow velocity vary from approximately +20% to –45% for flow rate  $Q_p = 18.2 \text{ m}^3 \text{ s}^{-1}$  and

approximately +20% to –40% for flow rates  $Q_p = 32.7 \text{ m}^3 \text{ s}^{-1}$ . In modification 2, the relative deviations of flow velocity vary from approximately +20% to –35% for flow rate  $Q_p = 18.2 \text{ m}^3 \text{ s}^{-1}$  and approximately +15% to –30% for flow rates  $Q_p = 32.7 \text{ m}^3 \text{ s}^{-1}$ .

## 4. CONCLUSION

The contribution describes the assessment of flow conditions in the intake structure of a small hydropower plant with bulb turbines by the means of a 2D numerical model. Overall the use of this model shows its suitability for a quick analysis of flow conditions in intake structures of SHPP.

The application of this method on the Stará L'ubovňa SHPP shows that there is a significant uneven distribution of flow velocities in the inlets of the turbine units.

The real geometry is compared with two modifications of the intake and the results are evaluated. The results are graphs of relative deviations of flow rates from the average flow velocity in the profile of screenings. Changes in flow homogeneity occurred in the profile of screenings, where modifications help to more evenly distribution of flow velocities. Modifications of intake structure also prevent the current to tear from the walls, creation of “flow shadows” and creations of vortexes.

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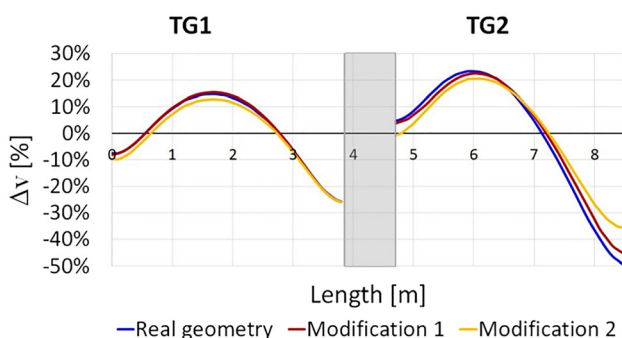


Fig. 10. Comparison of relative deviation of flow rates from the average flow velocity in the profile of screenings for  $Q_p = 18.2 \text{ m}^3 \text{ s}^{-1}$

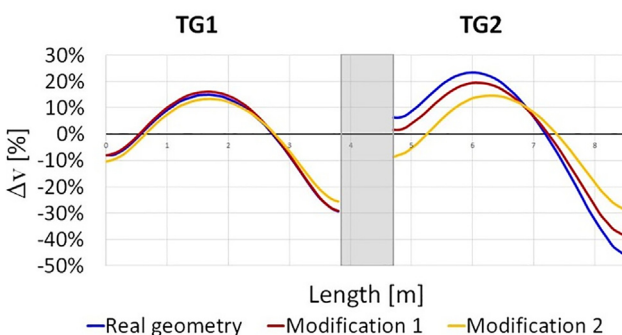


Fig. 11. Comparison of relative deviation of flow rates from the average flow velocity in the profile of screenings for  $Q_p = 32.7 \text{ m}^3 \text{ s}^{-1}$



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