# MODELING AS SUPPORT FOR THE IMPLEMENTATION OF THE PROJECT "RENEWAL OF THE TÖGING POWER PLANT"

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# ABSTRACT

The renewal of the existing diversion hydropower plant (HPP) Töging and its weir Jettenbach requires testing of several construction components. Therefore, physical and numerical modelling were performed. The construction phase for the weir was tested and significant parameters like flow velocities or shear stresses were determined. Parallel operation of both weirs, the old and the new one, are critical and had to be studied. The optimization of the stilling basins, flow pattern to the existing (residual water) hydropower plant, the scouring of the riverbed and new developed downstream fish passage structures were tested and optimized.

As mentioned already, the existing hydropower station Töging should be in operation during most of the construction phase. Thus, numerical and physical tests were carried out both in the upstream part and in the downstream reach to fulfil this requirement. To guarantee a most sustainable operation of the new power station for decades, approach flow to the turbines had to be optimized extensively. The application of numerical tools and physical models led to a successful implementation of the planning phase.

The above-mentioned downstream fish migration facility, which is needed today at many hydropower plants in Europe, is not yet state of the art and satisfactory solutions are sought in a variety of ways. In this project, a solution was found in a scaled physical model test by measuring and determining flow fields, which suggest that the downstream fish passage structures work.

Keywords: Hydraulic structures, hydropower, physical model test, numerical modelling.

#### **1 INTRODUCTION**

The energy provider VERBUND Innkraftwerke GmbH is planned the construction of the new weir Jettenbach and the powerhouse Töging on the river Inn in Germany as part of the project "Renewal of the Töging power plant" which is under construction now. The new construction is necessary due to the old-age of the HPP (commissioning 1924) forcing a re-commissioning and the associated technical needs for renewal. In Figure 1 an overview map of the area of the HPP as well as photos of the existing buildings are shown. The weir Jettenbach, which allows the withdrawal of water from the Inn into a 20-kilometer long artificial channel (Inn channel) heading to Töging, is located in Bavaria/Germany. The upstream water level is currently 403.35m a.sl. For the conceptual design of the new construction of the weir and for the water licensing procedure, the hydraulic boundary conditions are to be optimized for a newly requested 0.70m higher water level (404.05m a.sl). The withdrawn flow is increased from 340m<sup>3</sup>/s to 410m<sup>3</sup>/s.

The entire plant currently consists of a 6-field weir with double hook gates, two residual water power plants on each side of the river and the inlet structure to the Inn channel. The smaller residual water power plant, located on the left side, has been in operation since 1924 and produces an annual output of 1.1 GWh with a discharge flow of 7.3m<sup>3</sup>/s and a power of 0.4 MW. In 2004, a second residual water power plant was located on the right bank of the river (head 8.8m, power 5 MW, annual output 29.1 GWh and discharge 75m<sup>3</sup>/s). The newly built weir Jettenbach, which will have only 4 weir fields, is to be located about 50 m downstream of the existing weir.

The power house Töging, located at the end of the Inn channel, is characterized by a power of 85.3 MW with a discharge flow of 340m<sup>3</sup>/s and a head of 30.5m. The yearly energy output is 557.2 GWh. The new construction of the Töging hydroelectric power plant is located on the orographic right side of the existing powerhouse. After renewing the HPP, the power will increase to 110 MW and the annual energy output will be expected to be

677.2 GWh for the increased flow rate of 410m<sup>3</sup>/s and the hydraulic head of 31.1m. The planned investment costs are estimated to be around € 220 million (Gerauer, 2015).

Until the completion of the new buildings, the existing weir and power plant will remain in operation. This is a special challenge for the planners and contractors as well as for the operator during the construction phase.

In the planning phase the Institute of Hydraulic Engineering and Water Management of the Graz University of Technology was commissioned to perform physical and numerical modeling of the two parts of the plant. For the weir Jettenbach, a hydraulic sectional model, a hydraulic full model as well as accompanying supplementary numerical investigations of the planned new weir were carried out (Zenz et al., 2016a). The Töging powerhouse was examined in detail by means of a physical full model and two numerical models (Zenz et al., 2016b).



Figure 1. Location of the weir, channel and powerhouse, photographic impressions (source: Verbund)

## 2 METHODOLOGY

#### 2.1 Numerical modeling

The 2D and 3D numerical calculations for the reservoir and the weir for the flow during the construction phases at the power plant were carried out with the programs TELEMAC-2D and TELEMAC-3D. The programs are part of the open source software package TELEMAC-MASCARET for hydrodynamic and hydromorphological investigations. In order to achieve a detailed spatial resolution for optimizing the inlet area with the pressurized flow of the new power plant Töging, the 3D software CFX (ANSYS) was used.

The numerical investigations of the weir included the determination of the flow velocities, water depths and shear stresses for the individual construction phases, whereby the focus was on optimizing the height of the cofferdams. In addition, the stilling basin, the bed protection downstream of the stilling basin and the water levels during flood events were considered numerically to achieve a pre-optimization as an input for the physical model.

At the powerhouse, the approach flow to the turbines was optimized (3D) and the downstream and upstream parts during the construction phases (2D) were simulated.

#### 2.2 Physical modeling

In total, three models were built. Both the sectional model of the weir Jettenbach and the two full models Jettenbach and Töging (Figure 2) were modeled according to the Froude's Law of similarity. This model law

describes that the ratio of inertial and gravitational forces is the same in nature and in the model, giving a geometrically similar replication of free water surface flow. The chosen model scales are 1:30 for the sectional model and 1:40 for the two full models.

As a preliminary investigation, the weir itself, its gates and the stilling basin were optimized in a hydraulic sectional model in order to ensure optimal starting conditions for the full model and the numerical investigations of the Jettenbach weir. Subsequently, this model will not be handled in this paper.

The full model Jettenbach corresponds to a prototype length of almost 700 m. Upstream of old and the new weirs the model has a length of 11.1 m in the lab downstream about 5 m. The model has a width of about 4.7 m and a height of 0.65 m. The embankments and beds of the model were made of , like the weir pillars, the gates, the intake structure (bridge and baffle) for the diversion channel and the right bank residual HPP were made of plastics such as Plexiglas and Trovidur.

In the context of the experiments in the full model Jettenbach the following questions were answered: Behavior of the existing and the new weir system during the construction phases, optimization of the stilling basins and downstream bed protection measures, inflow to the residual HPP, log jamming of the existing weir and downstream fish migration facilities.

The modeled area of the powerhouse roughly corresponds to the natural length of almost 780 m with an inflow length of 380 m and a downstream length of 200 m. In the laboratory, the model had an upstream length of 9.8 m and the downstream area was about 5 m long. The new powerhouse was located in between with a length of 2.15 m, from the inlet to the draft tube. The old powerhouse was not modeled physically. The model had a mean width of 2.25 m and a height in the upstream diversion channel of 1.70 m, in the downstream part of 0.80 m. The construction phases of the upstream part were only considered numerically.

The investigations in the full-scale model of the powerhouse included the determination of the water levels in the downstream part during construction phases and the approach flow to the inlet structure.

In addition to the photographic and video documentation, the model tests mainly involved geodetic measurements of water levels as well as velocity measurements using ADV probes in the approach flow channel at the intake, in the trash rack plane and penstock as well as near the downstream fish migration facilities.



Figure 2. Physical models in the laboratory, left: old weir Jettenbach, right: new HPP Töging

# 3 RESULTS

Due to the large number of tests and numerical runs, only an excerpt of results can be shown here. Further results of testings can be found in Zenz et al. (2015), Schneider et al. (2016), Zenz et al. (2016a), Zenz et al. (2016b), Zenz & Schneider (2017), Schneider et al. (2018a) and Schneider et al. (2018b).

# 3.1 Power house (HPP Töging)

An important point for the planning of the powerhouse were the construction phases. On one hand, numerical calculations were carried out in the upstream reach, which did not result in exceptionally high flow velocities in the orographically right area at the existing turbine inlet. On the other hand, in the physical model, the dam depths in the downstream reach could be determined by simulating the existing power plant operation (see Figure 3).



Figure 3. Flow situation during the construction phases, left: flow velocities in the channel at the turbine inlets for the old HPP, right: downstream constriction due to cofferdams

The main focus of physical as well as numerical investigations was the approach flow to the turbine inlet for the new HPP. The flow direction to the existing power plant was relatively straight (Figure 3, left). Due to the arrangement of the planned new inlet on the orographic right side of the existing power plant, a stronger curvature of the channel was the result. Thus, a more pronounced spiral flow could be observed. Figure 4 shows the situation of the approach flow before its optimization steps. This could be confirmed in the physical tests too.





Several optimizations steps were undertaken to find the best solution for the approach flow was well as for the power descent to the turbines. Finally, the geometry of the channel and the inlet, the pressure shafts as well as the turbines themself (dimensions, position and elevations of turbines) were modified to get the smoothest and most uniform flow to the turbines. Figure 5 gives an example of flow measurements at the trash rack before and after optimization for turbine 1 (orographically left), during full operation of all three turbines. On the left side of Figure 5 the velocity fields before and on the rights side after optimization steps are shown. It can be seen that the flow field will be much smoother and better distributed along the inlet after modifications.



**Figure 5.** Velocity measurements at intake 1, full operation of all three turbines, colors show flow velocities in main flow direction (x), arrows indicate y- and z-directions

#### 3.2 Weir Jettenbach

# 3.2.1 Construction phase

The construction phases were carried out with the load cases (1) 100-year flood during winter (1437 m<sup>3</sup>/s), (2) runoff with 0.5 m free-board (1650 m<sup>3</sup>/s), (3) bankful runoff equal to 5-year flood (1750 m<sup>3</sup>/s), (4) 20-year flood (2200 m<sup>3</sup>/s) and finally (5) 100-year flood during summer (2850 m<sup>3</sup>/s). The water levels for the respective runoffs were measured at relevant and critical points. By installing a movable bed in the full model, taking into account the existing grain diameter in nature, the occurring scouring holes could be determined. Shear stresses, which serve as the basis for the dimensioning of bed protection, were calculated by means of numerical simulations.

Figure 6 shows as an example the numerically determined shear stresses besides flow situation during a 100-year flood in winter, whereas the postulated free-board of 1.2 m was fully exploited (top). Furthermore, the longitudinal water levels and the final scouring are illustrated (bottom).







Figure 6. Testing of a 100-year flood (winter) for a selected load case, visual appearance and shear stresses, water levels and scouring

#### 3.2.2 Stilling basin

The energy dissipation downstream of the existing weir did not work well, because no stilling basin was provided and thus uncontrolled scouring occured. The tests of the new weir in the full model were based on the results of the sectional model, as mentioned already. Hence, changes in length of the stilling basin were not necessary in the full model, only the depth and the downstream sill of the stilling basin had to be varied. However, an optimal variant including baffles could be found, guaranteeing that the energy dissipation takes place in the stilling basin to a large extent and thus the potential scouring in the downstream reach could be minimized. In the context of these tests the design criteria of the riverbed protection were defined (stone sizes and spatial extension of the bed protection). Figure 7 shows on the left side exemplarily a variant which did not work properly. The depth of the stilling basin was not sufficient and the danger of scouring downstream of the stilling basin was very high. On the right side of Figure 7 the final design of the stilling basin is shown. The energy dissipation happens within the stilling basin and the downstream bed was less susceptible for erosion.



Figure 7. Design of the stilling basin, left: bad variant – sill not working and high potential of scouring, right: final design of the stilling basin

#### 3.2.3 Log jamming

The intention of the operator was to retain the old weir, which is under a preservation order, and to construct the new weir parallel. However, our general assessment was that an accelerated runoff occurs with a functional old weir due to the local constriction and this will align the debris.

Now, if the new weir, which is located downstream, is in operation, this acceleration will no longer occur and the risk of log jamming is increased. Figure 8 shows an example of a jamming process during a 100-year flood (summer) and the calculated longitudinal water levels. The blue line shows the water level for the existing situation, the red lines for the time after constructing the new weir. The solid line shows the situation if the old weir would remain and the dotted line if old weir would be removed. It is obvious that keeping the old weir would increase the probability of over-topping levees and hence increase flooding probability.





## 3.2.4 Downstream fish migration

Knowledge of the upstream migration of fish is sufficiently available today for planning and building functional fish ladders. Regarding downstream fish migration, there is still considerable need for research, especially for potamodrome fish species. Nevertheless, on the part of the authorities the pressure increases to build downstream fish migration facilities in Europe. In the context of this project, technical solutions were proposed to offer the possibility of downstream fish migration via the left side near the drainage channel intake structure, both for bottom orientated and weak-swimming fish floating on the water surface. Fish experiments on the scaled model were not possible, only hydraulic aspects were examined. The functionality of the fish migrating facility has to be checked finally by monitoring the prototype. In the experiment, but also in the numerical model, the entrance structures were optimized with regard to their location. Three-dimensional velocity measurements have been carried out for this purpose. Seven variants were tested and a proposed design of the downstream fish migration facility was defined. Figure 9 shows on the left side the constructions and locations of the entrances for the fish. The right figure highlights the flow velocities in this area. The sectional cut is parallel to the intake structure of the diversion channel. The colors symbolize the flow velocities are in x-direction, meaning in main flow direction into the channel. Y- and z- velocities are indicated with arrows. The y direction is the main flow direction in the lnn river and heading positively to the weir.

On the water surface the velocities point to the direction of the weir and therefore it can be expected, that small fish has the possibility to follow the baffle that prohibits entering of debris into the main diversion channel and to find the entrance of the facility. The bottom-near oriented fish will follow the positive flow direction (y) to the bottom near entrance. The location was defined at a point before the y-direction changes and shows in the opposite side (against the weir).





Figure 9. Entrance structure for downstream migrating fish, both bottom oriented and near surface (left), Flow velocities, colors in x-direction, arrows indicate y- and z-directions, location of entrances

# 4 CONCLUSIONS

The optimization of the elevation of the cofferdams for the construction phase was carried out in numerical models for the upstream and downstream reaches and the findings were tested in the physical model for the downstream part as well.

Concerning the approach flow many modifications in the approach channel, at the intake and at the penstock were performed to get a better and smoother flow. Finally, a solution could be found where the flow to all three turbines could be harmonized.

During the construction period at weir Jettenbach, the existing weir will be still in operation and the old weir shall be removed only after completion of the construction. During this phases, there were some special features that have been extensively tested. Besides the determination of water levels, velocities and shear stresses, the tests also focused on log jamming of the old weir system. The determination of shear stresses were the input for assessing the grain sizes of the river bed protection and the measurement of water levels were necessary for defining the height of the cofferdams.

The design of the stilling basin was based on the results of the sectional model on one hand and on several tests in the full model on the other hand. The length and depth were determined, the functionality improved by installing baffles and the downstream reach secured by a proper scour protection.

The tests and calculations concerning log jamming of the old weir showed that the risk after the construction of the new weir increased significantly compared to the actual state if the old weir remains in the river. As a result of the construction of the new weir, the flow velocities decrease and the water levels increase, leading to a deterioration in the transport of driftwood through the old weir. Hence, the removal of the old weir was recommended.

With regard to downstream fish migration, several variants were tested and in the course of these experiments solutions could be worked out. These findings will give the fish the possibility to pass by the weir both at the bottom and at the water surface.

This contribution gives only a brief overview and an excerpt of results of many tests which have been performed during the project. However, good solutions could be found and it can be expected that the renewal of the existing diversion hydropower plant and its weir will be successful.

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