Side-channel spillway – Hybrid modelling

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ABSTRACT

The ÖBB-Infrastruktur AG owns 10 hydropower plants comprising large reservoirs in Austria. Detailed studies showed that the capacity of the spillway of the balancing reservoir Enzingerboden is not sufficient. The presented work deals with the adaptation of this side-channel spillway to the latest safety standards for extreme flood events. Its maximum flow rate is increased for about additional 100% of the actual design flow rate. The spillway channel with a fixed crest weir is located orographical right hand side is nearly perpendicular to the dam axis. It leads to a downstream chute located at the airside or the dam structure. Under current conditions, the limitation was the channel itself, unable to maintain an unsubmerged overflow for the adapted design flows.

The main goal was to increase the overall discharge capacity, considering limitations with respect to maximum allowable water levels in the reservoir. A full 3D-numerical investigation considering nearly half of the reservoir size was made to investigate the adapted channel geometry and effects back into the reservoir. In that course various design options, mainly combinations of channel inclination, abatement, wideing or shaping of the channel, were tested. In extend to the numerical investigation, the optimised geometry was used as the basis for a 1:20 lab scale model. Besides the validation of the 3D numerical results, the physical model test was used for testing additional enlargements and optimizations. The focus was on the behavior of the downstream chute and local adaptations influencing its flow conditions.

The presented work shows how (a) the 3D-numerical investigation can be an effectively used to minimise start up effort for the geometric optimizations in physical modelling and (b) how numerical and physical modelling fit and supplement each other.

INTRODUCTION

The 100% state owned ÖBB-Infrastruktur AG is proprietary of the railway infrastructure in Austria. The ÖBB-Infrastruktur AG, Business Unit Energy is responsible for the 16.7 Hz traction power supply in Austria, the energy supply of operational facilities and energy services such as energy metering. This company is owner of 10 hydro power plants in Austria.

At the beginning of the 20th century and in order to meet the growing electricity demand, the Austrian Railway (Österreichische Bundesbahnen, ÖBB) started with the planning of hydropower plants located in the Hohe Tauern in the Stubachtal in the province Salzburg. Between 1922 and 1991 the ÖBB constructed the hydropower plants Enzingerboden, Schneiderau and Uttendorf in the Stubachtal.

Figure 1: Balancing reservoir Enzingerboden *(upper left: reservoir Tauernmoos, upper right reservoir Weißsee).*

These hydropower plants comprise 5 concrete gravity dams forming 5 reservoirs with a total storage capacity of 78 million m³. Following the request of the responsible authorities the ÖBB-Infrastruktur AG assigned the Unit of Hydraulic Engineering, University of Innsbruck with the preparation of a study according to the Austrian Guideline for the verification of the flood safety of dams for all of these 5 reservoirs. These investigations proofed that the spillways of 4 of them have a sufficient capacity to the latest safety standards. Also this study showed clearly that the spillway of the balancing reservoir Enzingerboden is not properly designed for both the 5000 year design flood (170.5 m³/s) and the safety check flood (211 m³/s).

According to the basic idea of M. Schmitter the concept for increasing the capacity of the spillway of the balancing reservoir Enzingerboden was developed in close cooperation with the responsible authorities and their authorized experts.

The ÖBB-Infrastruktur AG assigned the Unit of Hydraulic Engineering, University of Innsbruck with the hydraulic numerical investigations and the construction of a physical model of this spillway. The results of this analysis were the basis for the final design of the spillway. The ÖBB-Infrastruktur AG received the construction permits of the responsible authorities in the beginning of 2012, the construction works started in April 2012 and will be finalized by the end of 2012.

CONCEPT

In parallel to the numerical investigations, the adapted design and the *safety check floods* (PMF) peak flow were estimated to be **170.5 m³/s and 211 m³/s respectively.** In a first approach a discharge of 240 m³/s was used as a first estimate. Simulations made in an earlier project dealing with the existing geometry showed a limiting capacity of nearly 100 m³/s identifying the side channel as the limiting factor. Different options were tested numerically first, leading to a significant expansion of the side channel having a discharge capacity of 240 m³/s. Complementary the numerical investigations a physical model was set up. Therein the adapted geometry based on the numerical results was tested with the help of a scale test. Extending the cases test numerical, different geometric variations in the side-channel and the chute were realized. From a hydraulic perspective the permissible reservoir filling and the over toping of the chute side wall were limiting factors. Structural limitations constrained the attack into the side walls, channel sloping or widening. Finally a well suited geometry was found, considering hydraulic, structural as well as cost aspects.

The comparison of the numerical and physical results as well as the boundary conditions will be main part of the presentation.

NUMERICAL MODEL

For the numerical calculations the commercial 3D-numerical software FLOW-3D v.9.4.2 (Flow Science, 2010) is used. The grid is build up with six rectangular blocks, which reach up to nearly 4 million cells (50% active cells, Fig.2 left). The minimum grid size is 0.125 m in each direction and the whole model covers an area of 70 m by 150 m. The computed FAVORized geometry is shown in Fig.2 on the right side.

The water is added through the bottom of the last block. As a finish condition the water level in the reservoir is monitored. Water level and velocity fields are evaluated in the post-processing when the simulation reached steady state conditions.

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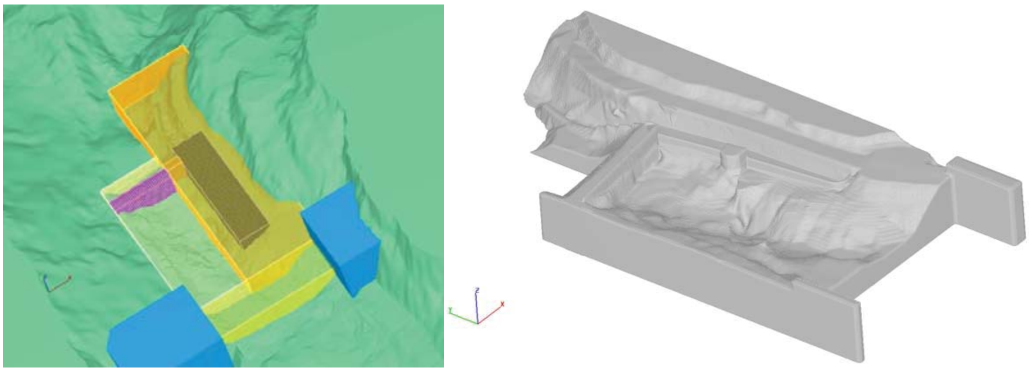

Figure 2. Grid (left) and FAVORized geometry (right).

Figure 3 shows an exemplary result of the numerical simulations (for Q=170 $m^3/_s$) where the color coding represents the fluid depth with an upper limit of 5 m. A similar evaluation was made for various discharge stages being investigated.

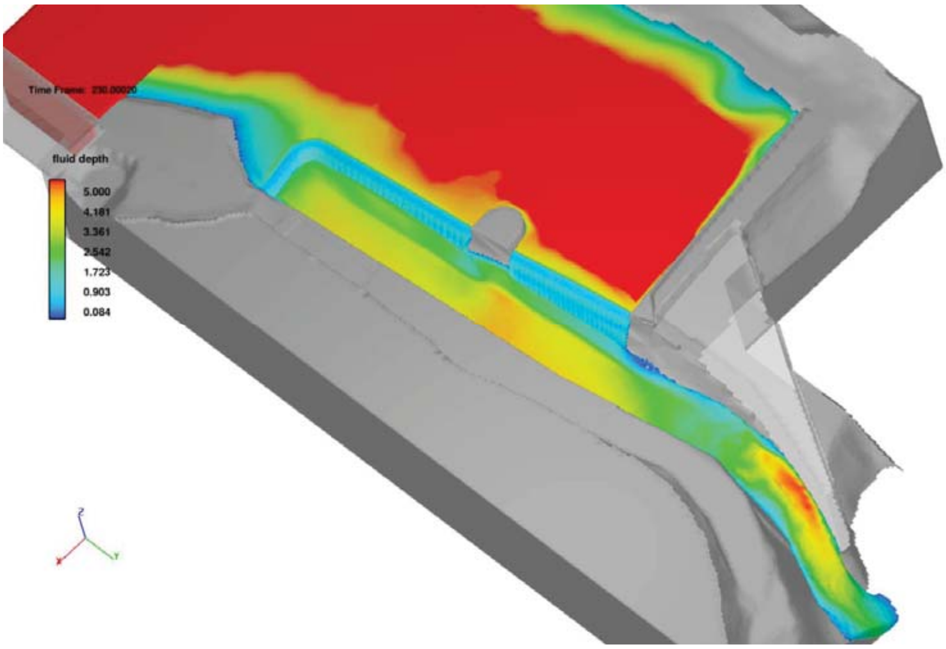

Abb. 1 Exemplary numerical result Q=170 m^3/s, water depth limited by an upper boarder of 5 m

PHYSCIAL MODEL

Based on the numerical results the velocities near the weir are very small. The influence of the ground in the reservoir is negligible. A scaled version of the geometry in addition to the boundaries of the physical scale test is shown in Fig. 4. Hence, the physical modeled geometry can be reduced to the weir including the side-channel and the spill way (Fig. 5). Consequently the physical model could be build at a larger scale allowing a better and more detailed reproduction of the hydraulic behavior of the structure.

With the help of the measurements in the physical model the numerical calculation could be validated and it was possible to come to a very good compromise between building costs and hydraulic capacity of the side channel. Hydraulic limitations considered in the tests were the reservoir water level as well as the over topping of the chute side wall downstream the spillway.

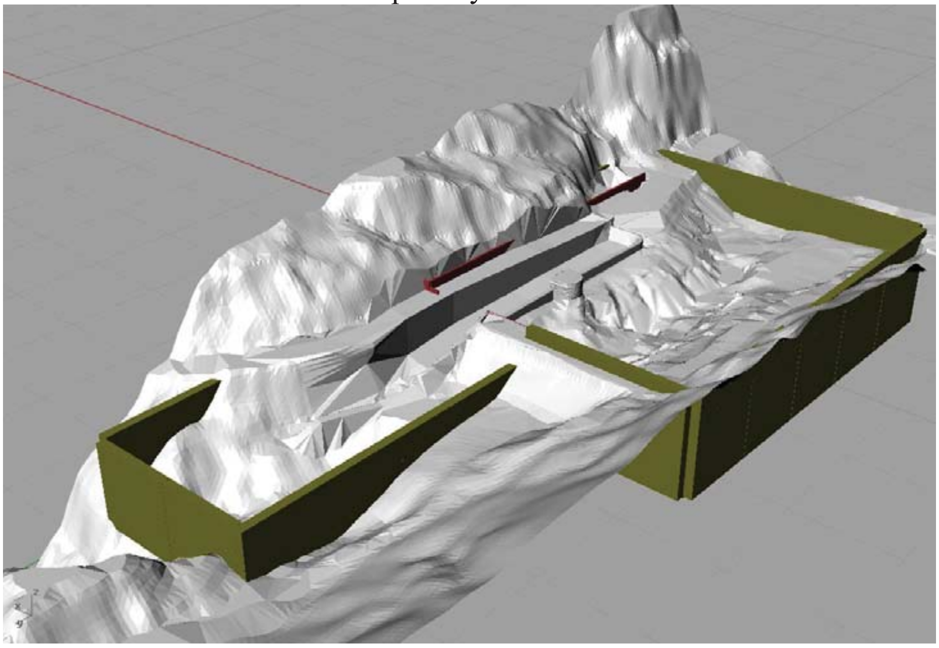

Figure 4. Scaled geometry of the reservoir including the boarders of the physical scale model.

CONCLUSIONS AND RESULTS

In Figure 5 the testing of the downstream chute is shown, using two different geometrical setups for the transient section between spillway and chute. Where the overtopping of the upper sidewall of the chute is still the case for the baseline setup (see Fig. 5, left), the overtopping is widely stopped for the final geometry (Fig. 5, right).

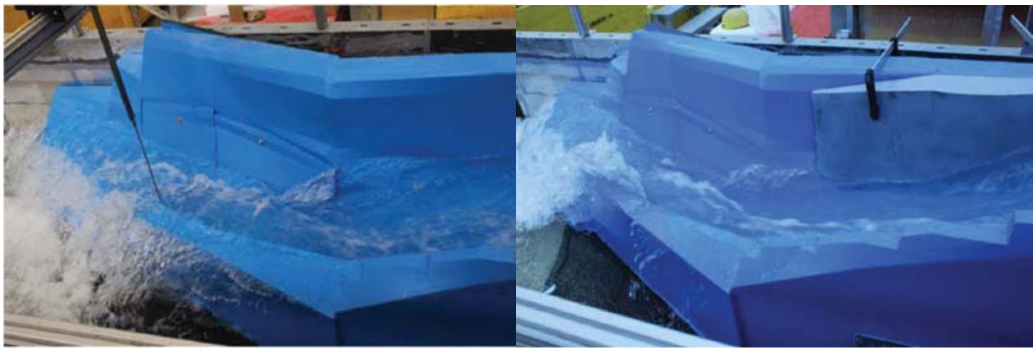

Figure 5. Measurement of waterlevels and overtopping behavior at the chute with baseline geormetry (left) and final geometry (right).

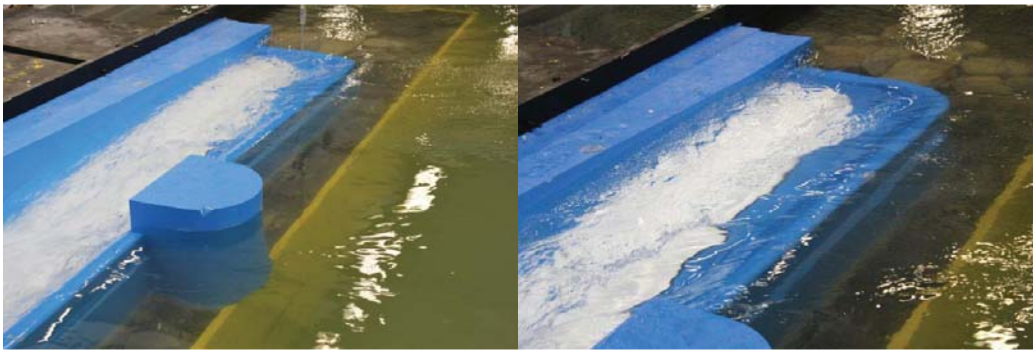

Figure 6. Exemplary results of the laboratory test.

In Fig. 6 the upstream situation at the spillway using the final geometry is shown. The widening of the spillway has proofen to be sufficient to provide the discharge capacity for the PMF peak flow. Even an increased discharged compare to the PMF is possible to be diverted. The weir overflow from the basin to the spillway ranges from a free to a partially submerged overflow. This effect could as be simulated in the physical and the numerical model. For the given case, the combined application of a numerical and physical model was shown. The numerical investigation is thereby a vital tool for the exploration of the required model dimensions in the physical model. Nevertheless, the physical model has been applied to investigate as well complex geometry, as it is the case at the downstream chute. It is shown that even complex flow is reproducible reliably by the numerical model, which increases the trust in the reliability of numerical 3D modeling.

REFERENCES

Flow Science, Inc. (2010): FLOW-3D Version 9.4.2, user manual.