Numerical 3Dmodeling and optimization of technical measures to reduce sedimentation inside lakes

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1. Introduction

The accumulation of sediments is a major problem affecting nearly all reservoirs around the world. Regular flushing, dredging and use of landfill areas are used as measures against sedimentation. Therefore, a sustainable solution has to be found. This paper describes an ecological technical measure applied for the sediment management of a shallow reservoir using a numerical simulation which is based on finite volume analysis. An application of this simulation is presented for Lake Gübsensee located in the Canton of St. Gallen, Eastern Switzerland.

2. Problematic, Data used and Objective of the study

The Gübsensee reservoir has a maximum length of 1’165 m long and a maximum width of 265 m wide while the average depth is 12 m but decreased to 5 m in front of the two inflow galleries due to sediment deposits. These two galleries, diverting waters from two upstream rivers into the reservoir, are feeding the lake with water while there is one power intake on the opposite shore (Fig. 1.).

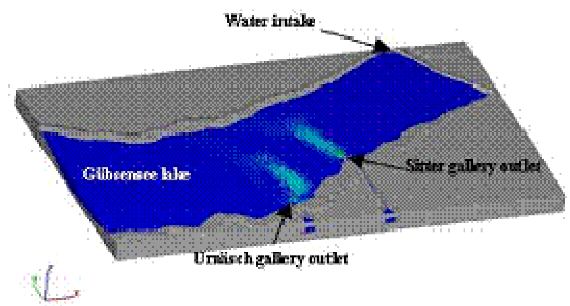

Fig. 1. Numerical model showing main components of the reservoir

The reservoir is a daily storage type where water level fluctuates by 1.58 m every day (from 682.28 m a.s.l to 680.70 m a.s.l). Two main upstream water courses feed the Gübsensee Lake (Fig. 3) with similar flows which are 0.5 - 4.6 m3/s (min. /max. discharges for the Sitter River) and 0.5 - 4.7 m3/s (min. /max. discharges for the Urnäsch River). These discharges vary depending upon the amount of snow melt and rainfall. The hydroelectric power plant consists of 3 turbines. Two of them have useful discharge range of 4.0 - 8.0 m3/s while the third one has useful discharge range of 0.5 - 2.0 m^3/s.

A survey study shows that the reservoir has lost 25% of its 1.47 million cubic meters of water storage capacity in the past 90 years but this figure is more important concerning the effective region of the lake (where the power intake and the gallery outlets are located) at the north eastern part where the volume loss reaches around 50%. Both galleries have upstream sand traps to collect sediments carried by water flow. Materials trapped in these sand traps need to be evacuated when it is filled. Furthermore, fine sediments passing the sand traps are carried by the water flow down to the reservoir.

The study focuses on analyzing the flow velocities magnitude field and its influence on the sediment transport for different exploitation scenarios. Also, using numerical 3D modeling, different technical solutions were studied and validated and finally, the optimization and the design of the retained solution were carried out. According to the geometry of the Gübsensee Reservoir and in order to limit the accumulation of sediments, two main ideas have been adopted. On one hand the galleries outlet walls will be reoriented to direct the flow from the two galleries to the electric power plant intake. On the other hand, several artificial islands will be used for guiding the flow and increasing the flow velocity inside the reservoir.

3. Samples Sieve analysis & critical velocity determination

The critical velocity is the velocity at which the fine or the coarse sediment begins to be deposited when the flow regime is in transition from suspension flow to deposition of flow. To determine this value, it was essential to have the grain size distribution for the sediment particles to determine the characteristic diameters such as d_{90} or d_{85} or d_{50}. To define the erosion-transportation-deposition criteria for uniform particles, the Hjulström diagram (1935) is useful to determine the water velocity required to carry a certain sediment size in suspension.

Thanks to two samples taken from both galleries outlets, the sieve analysis was performed and grain size distribution drawn for each sample.

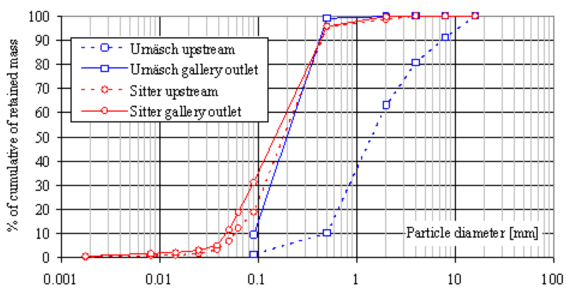

Fig.2 . Sieve analysis for samples taken from galleries outlets and upstream

The water velocity required to carry 90% of fine particles is determined in Hjulström diagram as 3 cm/s (Fig.4.). To stay in the safer side, a water velocity of 4 cm/s was adopted as the critical velocity to secure water flow during its trajectory from the outlets galleries to the water intake of the hydroelectric power plant.

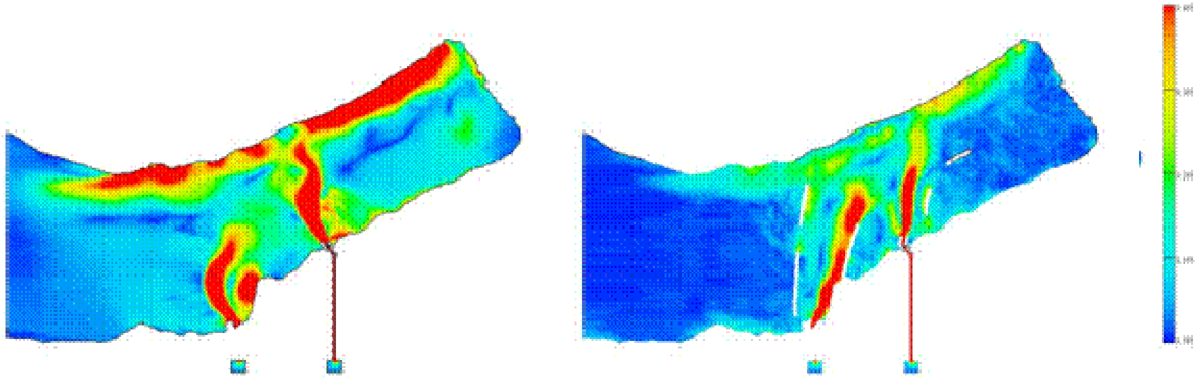

Fig. 3. Flow velocity magnitude field of the (a) actual situation, (b) Proposed measure (with submerged guiding walls). Velocity scale from 0.0 to 0.4 m/s

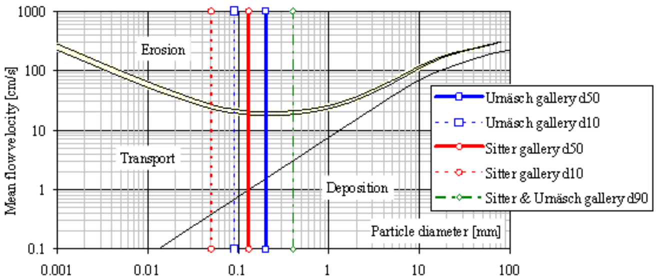

Fig. 4. Determination of critical velocity from Hjulström diagram [After Hjulström taken from Graf 1984].

3. Proposed measure, results and discussions

Depending on results shown in the simulation of the actual situation (Fig. 3a), two essential goals were fixed to enhance the flow behavior and velocity field towards the water intake of the reservoir. First, it is important to reduce water sediment laden flow entering the western part of the lake and second is to link the inflows from the two galleries outlets towards the water intake. The following measure was proposed. Firstly is to reorientate of galleries outlet walls towards the water intake of the hydroelectric power plant. Secondly is to construct artificial islands following the thalweg line with piles 2 meters below the minimum operating water level combined with outlet gallery newly aligned walls.

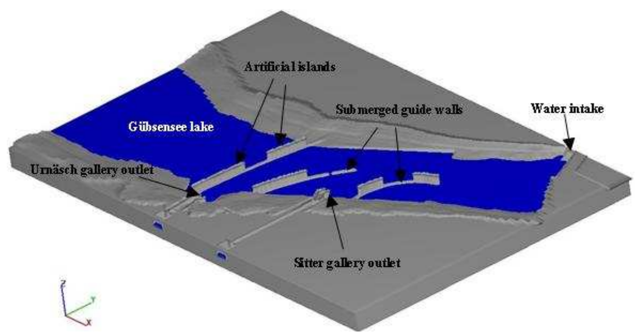

Fig. 5. FLOW-3D® model showing the submerged guiding walls combined with the five artificial islands, visible thanks for lowering top water level to 677.7 m a.s.l one meter below the wood submerged guiding walls top level (678.7 m a.s.l).

Three main inlet and outlet discharge conditions are the governing factors for flow in the reservoir. Flow inlet and outlet scenarios are 2.0, 8.0 and 9.3 m^3/s inflows respectively with 2.0, 8.0 and 18 m^3/s outflows (turbines working 24 hours per day which is a special case for this reservoir). According to these scenarios, the scenario for equal inlet and outlet flows was chosen as numerical stability calculation to determine the flow behavior (scenario: 8 m^3/s inlet flow and 8 m^3/s outlet flow)

The proposed measure shows a more concentrated flow field magnitude from the galleries towards the power intake (Fig. 3b). The flow percentage reaching the reservoir outlet from the reservoir inlet has been increased significantly from 23% to 35%. This result will lead to 50% improved efficiency of sediment transit through in the lake

5. Conclusions

This paper presents an ecological measure for the sediment management of a hydropower plant reservoir. This measure is composed of artificial islands with submerged wooden piles guide walls which could be useful to help the operators to improve the sediment management situation. Furthermore, the construction of such small islands offers major opportunities as a nesting and breeding site for birds and amphibious animals. The specific ecological conditions of such a site attract migrating and wintering birds due to the absence of direct human disturbances. This measure has therefore a significant ecological advantage as it could be an environmentally integrated solution. The results obtained in this paper could serve as a guiding idea for other shallow reservoirs around the world.

References

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