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Multi-phase flows at hydraulic structures: water-sediment, air-water and water-structure-fish interaction

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1. Introduction

In many industrialized countries a considerable share of today's hydraulic infrastructure was constructed during the economic boom following World War II. Irrigation and drinking water transfer systems, reservoirs, hydropower dams and systems, river training works, flood protection infrastructure, etc. have aged considerably since then, often reaching the end of their design life and thus needing refurbishment. Today's requirements in terms of safety, durability, economy and ecology have resulted in new challenges in the design and construction of hydraulic infrastructure. Sediment issues like reservoir sedimentation have increased in importance after decades of operation, so that measures to mitigate their effects are needed (Fig. 1). High-speed flows in dam safety related structures result in significant aeration and require an adequate design to increase operational safety. Moreover, the impact of hydraulic structures on the aquatic fauna has gained considerable attention in today's water legislation, demanding for example for undisturbed fish migration across transverse structures such as weirs, sills and hydropower plants in up- and downstream directions. As a consequence, the interdisciplinary domain of ethohydraulics has recently emerged, combining the behavior and response of the aquatic fauna – particularly of fish – to the hydraulic signatures created by the flow.



Figure 1: Aggradation pattern in Gries reservoir, Switzerland, with lowered reservoir level during construction works at the dam (on the left) on 2 July 2015 (Photo: D. Ehrbar)

2. Outline of keynote lecture

At the Laboratory of Hydraulics, Hydrology and Glaciology of ETH Zurich, a number of research projects deal with the challenges mentioned above, and main findings are given in the keynote presentation.

Sediment bypass tunnels and channels are a means to counter reservoir sedimentation and to reestablish sediment continuity at reservoir dams. Due to intense loading by sediment-laden high-velocity flows, their invert wear is considerable and costly. To lower maintenance and refurbishment costs requires both an optimum hydraulic design and the use of abrasion-resistant invert materials. The state-of-the-art abrasion models are presented and discussed based on both laboratory and field studies.

Bottom outlets are key safety devices of high-head dams serving the main purpose of controlling the reservoir water level. The high-velocity free-surface flow downstream of the bottom outlet gate leads to considerable air entrainment and air transport. To avoid negative pressures and consequently prevent problems with gate vibrations, cavitation and flow chocking, a sufficient amount of air has to be supplied through an aeration chamber. Existing approaches to predict the air demand of bottom outlets show a large scatter and the knowledge on the transition from free-surface to fully pressurized flow is still scarce. The overarching goal of an ongoing study is to improve design guidelines by

means of a systematic large-scale physical model investigation. In addition, numerical simulations are performed and field experiments are conducted at two Swiss high-head dams to tackle the important issue of scale-effects. Recent results are presented in this keynote.

Downstream fish migration is a relatively novel domain in hydraulic engineering, requiring new solutions to protect descending fish from becoming injured, for instance at hydropower turbines. The use of mechanical protection systems like fine-screened horizontal bar racks or of behavioral systems like vertical bar racks, both combined with bypasses as alternative migration corridors, is a promising concept, for which there are still a number of open questions: What are the head losses of such structures, especially when parts become obstructed by floating debris? How can the guiding efficiency for endemic potamodromous species be optimized in terms of layout and hydraulics of racks and bypasses? How can sedimentation in front of these fish guiding structures be prevented? How can the racks be efficiently cleaned even for very long structures at large hydropower schemes? New findings of ethohydraulic studies at VAW that tackle these issues will be presented.