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Analyzing Water Waves in Underground Pumped Storage Reservoirs: A Combined 3D Numerical and Experimental Approach

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Abstract : By today underground pumped storage plants as an outstanding alternative for classical pumped storage plants do not exist. They are needed to ensure the required balance between production and demand of energy. As a short to medium term storage pumped storage plants have been used economically over a long period of time, but their expansion is limited locally. The reasons are in particular the required topography and the extensive human land use. Through the use of underground reservoirs instead of surface lakes expansion options could be increased. Fulfilling the same functions, several hydrodynamic processes result in the specific design of the underground reservoirs and must be implemented in the planning process of such systems. A combined 3D numerical and experimental approach leads to currently unknown results about the occurring wave types and their behavior in dependence of different design and operating criteria. For the 3D numerical simulations, OpenFOAM was used and combined with an experimental approach in the laboratory of the Institute of Hydraulic Engineering and Water Resources Management at RWTH Aachen University, Germany. Using the finite-volume method and an explicit time discretization, a RANS-Simulation (k-ε) has been run. Convergence analyses for different time discretization, different meshes etc. and clear comparisons between both approaches lead to the result, that the numerical and experimental models can be combined and used as hybrid model. Undular bores partly with secondary waves and breaking bores occurred in the underground reservoir. Different water levels and discharges change the global effects, defined as the time-dependent average of the water level as well as the local processes, defined as the single, local hydrodynamic processes (water waves). Design criteria, like branches, directional changes, changes in cross-section or bottom slope, as well as changes in roughness have a great effect on the local processes, the global effects remain unaffected. Design calculations for underground pumped storage plants were developed on the basis of existing formulae and the results of the hybrid approach. Using the design calculations reservoirs heights as well as oscillation periods can be determined and lead to the knowledge of construction and operation possibilities of the plants. Consequently, future plants can be hydraulically optimized applying the design calculations on the local boundary conditions.

Keywords : energy storage, experimental approach, hybrid approach, undular and breaking Bores, 3D numerical approach
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