Modelling flow-induced vibrations of gates in hydraulic structures

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Summary

The dynamic response of gates of hydraulic structures caused by passing flow poses a potential threat to flood defence safety. Complex interactions between the turbulent flow and the suspended gate body may induce undesired vibrations, a process that is not readily assessed or captured in design rules. This thesis contributes to a better understanding and prevention of the gate vibration problem by building on previous research and proposing new solution approaches.

A physical scale model experiment was conducted to investigate cross-flow vibrations of a vertical-lift gate with underflow. This was done for two profiles: a standard rectangular profile and an adapted profile with ventilation slots added. Under submerged conditions and at small openings, the ventilated gate showed significantly reduced vibration amplitudes, this is shown most profoundly for the dimensionless reduced velocity V_r in the range $2 < V_r < 3.5$. The data obtained from the experiment were used for validation of physics-based numerical simulations with the finite-element method. An arbitrary Lagrangian-Eulerian mesh enabled a transient analysis of the local flow field, boundary pressures and the resulting motion. The simulations give insight into how the leakage flow of the adapted gate type diminishes the observed movement-induced excitation of the flat-bottom gate at $V_r \approx 10$: by suppression of entrainment from the wake which is held responsible for pressure fluctuations close to the trailing edge.

With the moving mesh applied in a different way, numerical simulations were made of the free surface. It is shown how these non-hydrostatic computations of the flow around a fixed gate can aid in the prediction of gate discharges – something that larger system-scale models often omit. In particular, numerical tests illustrate how this may support operational decisions of gate opening and closure, optionally using automatic control, such that discharges and local flow velocities have minimal detrimental impact regarding scour, ecology and vibrations.

The installation of sensors on hydraulic structure gates constitutes a promising new way of avoiding critical vibrations, as introduced in this work. A data-driven system is outlined where continuous monitoring of accelerations fills a database. Machine learning is then applied to classify the observed amplitudes as a function of gate opening and dimensionless reduced velocity, thus training the system for evaluation of future states. The proposed control system is aimed at a timely recognition of the risk of flow-induced vibrations, so that suitable operational measures can be taken.

In addition to the use of the measured vibration data for validation of a physics-based simulation model and for demonstration of control options, a third use is explored as well. Evolutionary computing comprises a class of heuristic computational methods that has recently started to reveal its huge range of possibilities. In this thesis, the differential evolution algorithm is used to identify the coefficients of second-order differential equations from time signals. Of special interest is the identification of self-excited oscillations, the most

harmful type for gates in hydraulic structures, which typically contain non-linear damping terms. Numerical experiments of the proposed method assume equation structures and use the velocity only at the first time step. It is furthermore shown how the technique can be extended to recover the motion equation from only the support force signal. Intended applications are pinpointing self-excited vibrations for early-warning purposes and the analysis of intractable non-linear systems in general.

In the more abstract final chapter, the same differential evolution algorithm is applied to derive numerical solver schemes for differentiation and integration problems with known solutions. The coefficients of finite difference formulae and a number of single and multi-step integration methods are generated. Most interestingly, new fifth-order Runge-Kutta schemes were reverse engineered with remarkable accuracy using the set of order condition equations for fitness evaluation. This part of the study could be valuable for future developments in the design of advanced numerical methods.