FLOW-INDUCED VIBRATIONS AT HYDRAULIC STRUCTURES

by

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ABSTRACT

Despite of remarkable research during the last decades, such as Naudascher and Rockwell (1994) or Kolkman and Jongeling (2007), flow-induced vibrations still cause problems in hydraulic engineering. Vibrations occur not only at old gates, but also at new gates, such as radial gates or filling valves at miter gates. Against this background a research and development project was initiated in the Federal Waterways Engineering and Research Institute in order to analyze the different causes by field measurements and by the use of numerical models. The aim is to identify the excitation mechanisms and to improve the current construction standards (Göbel et al., 2018). Studies are presented, where gate or gate parts were excited to vibrations by fluid-structure interaction. Typical frequencies are presented for the vibration of hydraulic gates, for spring supported sealing systems and for rubber seals. The frequencies are helpful for operators to identify the source of vibration in order to initiate constructive or operational improvements.

Due to the relatively high elasticity of long span gates, bending vibration might occur, if the gate is excited to vibrate by under- or overflow (Ishii and Knisely, 1992). One example is a weir on the River Weser in Northern Germany, where vibrations could be observed after opening the gate for a few centimeters. A resonance frequency of 1.5 Hz could be determined for the 42 m wide lifting gate. In an experimental testing a predominant bending vibration mode could be identified with a characteristic wave pattern upstream of the gate (Fig. 1a). Numerical studies were used in order to identify the critical opening widths in combination with the downstream water level.

(a)

(b)

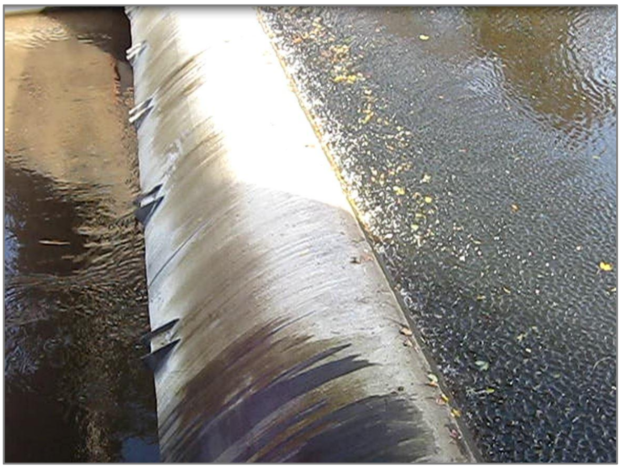

Figure 1: (a) Vibration of a lifting gate with upper flap gate and (b) of a sealing system at a submersible lifting gate

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Typically, gates vibrate in a single-digit frequency range (Fig. 2b & d). If underflow gates are equipped with spring supported sealing systems, where the sealing acts against the water pressure, they generally tend to vibrate in closed or slightly opened position because they are elastically mounted. These constructions are pretty diverse and thus the resonance frequency may vary between the different systems. Experiences show that the resonance frequency is significantly higher in a range between 15 and 40 Hz. Figure 1b shows the wave pattern caused by a vibrating spring-supported seal system.

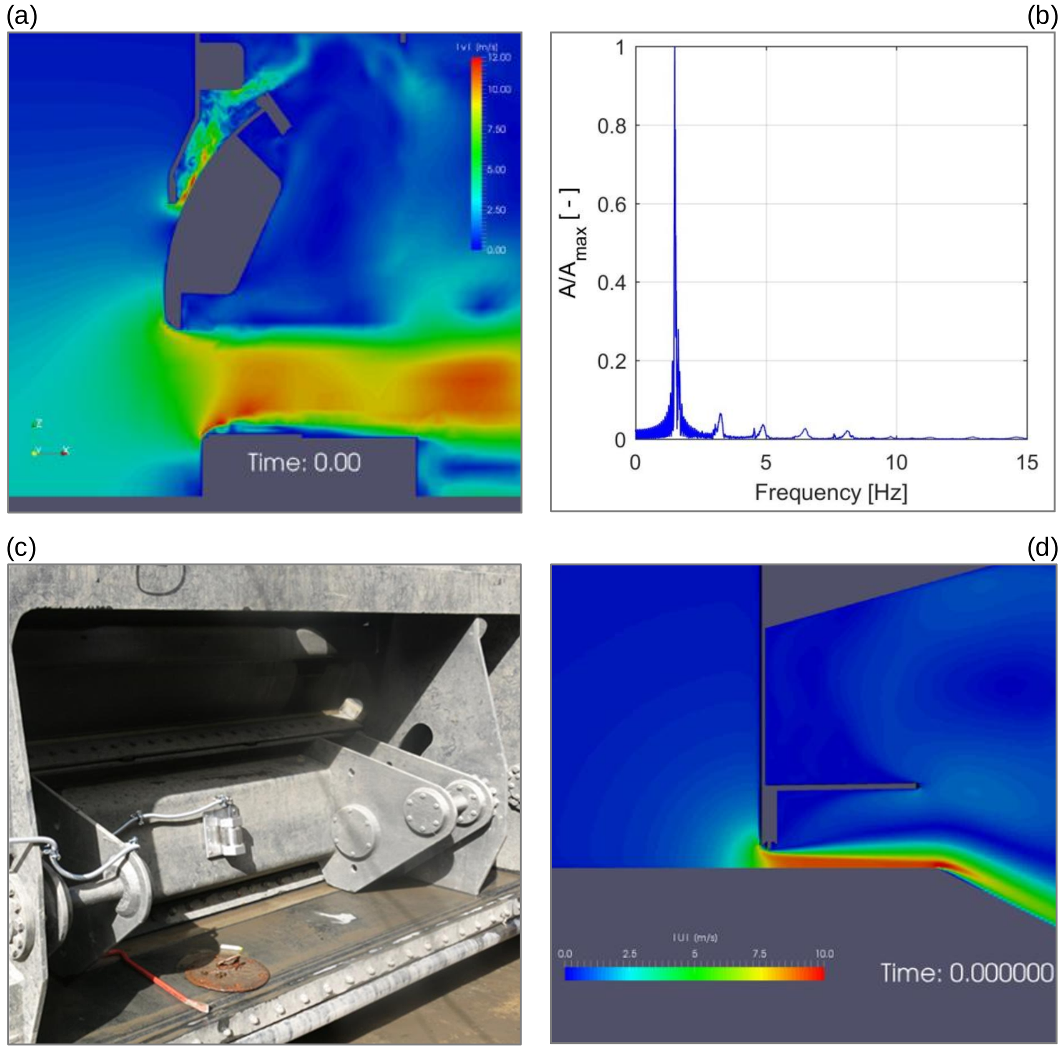

Figure 2: Applied methods: (a) numerical simulation of a filling valve; (b) Frequency analysis of a measuring signal; (c) acceleration sensor at filling valve of a mitre gate and (d) numerical simulation of fluid-structure interaction of a lifting gate

Seals in the shape of a musical note have multiple advantages if they are installed properly. The flexibility of the rubber makes the seal adaptive to uneven surfaces and tightness can be improved. Naudascher and Rockwell (1994) mentioned already that J-seals can also be a source of flow-induced vibrations during small openings or leakage. Seal vibrations occurred at a new miter gate on the river Neckar (Fig. 2a). During commissioning heavy vibrations occurred when the filling valve was opened a few centimeters. Intensive in-situ measurements were carried out to identify the source of vibration (Fig. 2b). Sensors were applied on different positions of the radial gate which showed a matching dominant frequency of 40 Hz. By comparing the signals it could be concluded that vibration was induced at the top sealing. Therefore, the construction was improved. Another example of seal vibrations is a new radial gate with upper flap gate. During commissioning loud humming vibrations were noticed at small opening widths. In order to determine the resonance frequency of the vibrations, the sound track of a video was analyzed. The dominant frequency was 37 Hz, which fits quite well in the known frequency range of 35 to 50 Hz for vibrating J-seals. After removal of the J-seal, the buzzing vibration was gone.

In addition to field measurements and physical models numerical simulations of fluid-structure interaction (FSI) is a very promising method to analyze problems and to improve constructions. First applications are presented. Typically, two standalone solvers for the fluid and for the solid region are used. On the interface of the two regions, an information exchange between the solvers is required. Viscous and pressure forces from the fluid region will be set as boundary conditions for the solid region and deformation of the solid region will be set as boundary condition for the fluid region. This method is called partitioned approach and is used in the solver package fsiFoam that can be included in OpenFOAM® (Göbel et al., 2017). Numerical methods are advantageous because they allow the evaluation of flow parameters at locations which are hardly accessible on site or even in a physical model.

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