



Numerical analysis of hydrodynamic forces due to flow instability at lift gate

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A numerical method, being a combination of the vortex method and the boundary element method, is used here to predict the two-dimensional flow field in the vicinity of an underflow vertical lift gate. In practice, tunnel-type flat-bottomed lift gates experience strong hydrodynamic loading, due to vortex detachment from the gate bottom edge, and near-wake velocity fluctuations. This paper presents a stream function, and velocity and vorticity distributions for two gate gaps. The vortex detachment mechanism is described and the vortex shedding frequency, expressed as a Strouhal number, is presented. The predicted velocity and vorticity fields are then used to calculate the pressure distribution on the gate surface by the boundary element method. The time histories of the lift and drag coefficients are presented. The proposed numerical method has been validated by the measurements of the downpull coefficient for the flow around the lift gate.

Keywords: *vorticity, vortex method, flow instability, vertical lift gate, boundary element method, hydrodynamic force*

1. Introduction

The calculation of hydrodynamic forces on hydraulic gates is a major problem which designers involved in hydroengineering face. When the flow around the gate is unstable, a changeable hydrodynamic load arises, which may result in vibrations of the gate, influencing its operational reliability and safety. This unfavourable phenomenon occurs predominantly at the high head gates of dams and hydropower plants. The most widely used high head gates are vertical lift gates or radial gates, working as regulating (partially opened) gates or as emergency and guard gates during opening and closing. In this paper the case of a lift gate with a submerged and pressurized underflow space is investigated.

The instability of the stream flowing under the gate depends mainly on the shape of the gate lip from which the shear layer is separated. The mechanism of this instability stems from the changeability of the layer separation point and from the fact that the shear layer impinges on the protruding gate elements.

When the stream flowing under the gate is unstable, the resulting pressure fluctuations cause the hydrodynamic force to fluctuate too. The latter's downpull component has been the subject of numerous researches and experiments by among others: Simmons [18] who conducted tests (based on the air model) on the flow around the gate,

Colgate [5] who carried out downpull pattern tests and natural measurements, and also Sagar [17] who suggested various lift gate designs. The fluctuations in the hydrodynamic force are the cause of flow-induced vibrations. Many studies have been undertaken to determine this mechanism and the optimum lower edge shape minimizing flow-induced vibrations (e.g. Campbell [4], Naudascher [14], Hardwick [9], Kolkman [10] and Thang [19]). In the case of gate underflow, the most common cause of vibration is the instability of the single layer separating from the gate lip (the instability induced excitation mechanism), see: e.g. Naudascher [16] and Naudascher & Rockwell [15]. Experimental research into this mechanism for a rectangular plate with two degrees of freedom was done by Billeter [1, 2] who found that the vibrations were caused by two phenomena: the streamline impinging-leading-edge-vortex (SILEV) mechanism and the instability of the shear layer (ISL) in the tail water. The phenomena result in the pulsation of the pressure acting on the gate's bottom and rear edges. Typically the unstable flow is determined numerically or analytically and the hydrodynamic forces are calculated by integrating the pressure distribution over the gate area.

This paper presents a numerical method for analyzing the aforementioned phenomena by interpreting the velocity, vorticity and pressure fields.

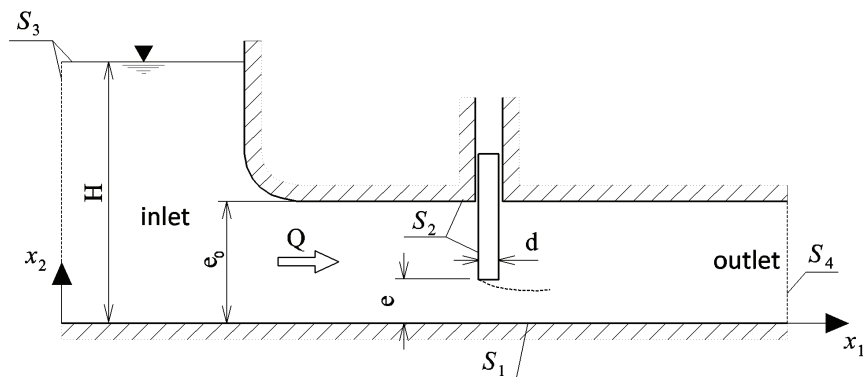


Fig. 1. Channel and gate parameters

It is very difficult to model the velocity field because of the strong turbulence generated at the gate. Moreover, as vortical structures separate from the boundary layer a recirculation zone forms behind the gate. This paper describes how to use the vortex method to analyze fluid motion instability under the lift gate and the boundary element method (BEM) to calculate the pressure. A scheme of the gate is shown in Figure 1.

2. Mathematical basis

A flat incompressible viscous flow is described by the Navier–Stokes (N–S) equation which through rotation can be transformed into the Helmholtz equation. As a result,

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