LES simulation of flow around dam gate section

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Contents

1. Motivation and timeliness

Several times a year Saint Petersburg experiences floods. The project of dam construction was designed to prevent the Saint Petersburg city from periodical inundations. Now this project is partly realized and the dam is almost finished (see Figure 1). Only a small part of the dam needs to be constructed. Exactly in this place the ship-passing channel is planned. The width of the channel is about 200 m and the depth is 16 m.

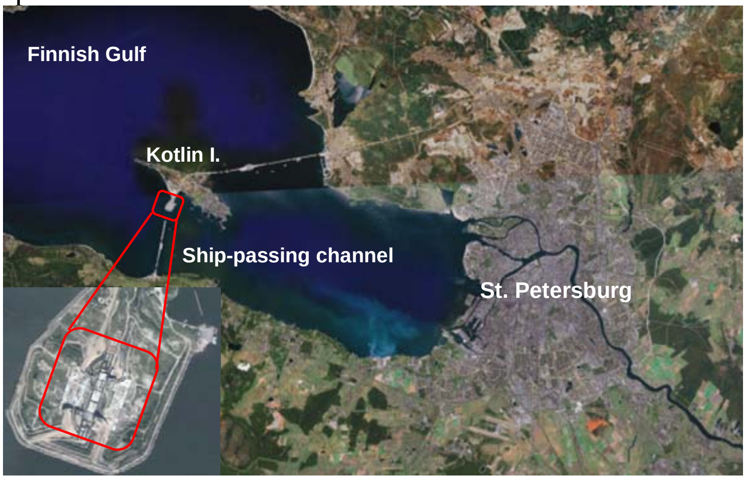

Figure 1 *the satellite photo of the eastern part of the Finnish gulf and Saint Petersburg city*

At the menace of flood the channel is closed by two gates having the form of pontoons (see Figure 2). The gates are moved to the center of the channel and then submerged.

The model tests disclosed that in some regimes the huge oscillations of gates are observed. This technical problem significantly decreases the reliability of whole Saint Petersburg flood defense system. The failure in gate system operation can result in heavy material and life losses in the case of disastrous flood. Also the blocked ship passing channel will make it impossible for ships to get into the city port.

The first mathematical simulations of the flow over gate section that were performed in the St. Petersburg Polytechnic University [1] permitted to discover the reason of these oscillations. The oscillations were caused by the turbulent vortex shedding from the lower edge of the gate. The mathematical model was developed for simulation of the gate section movement under loads from the flowing water.

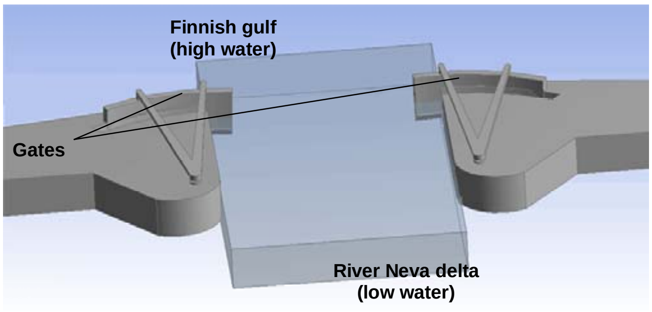

Figure 2 *The gate system (CAD model)*

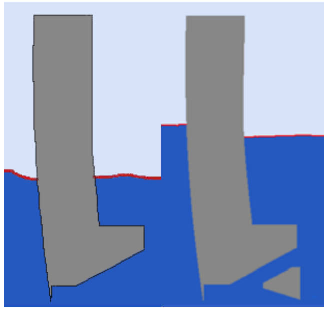

Figure 3 *Initial (left) and revised (right) constructions.*

After that construction of gates was revised – by results of physical experiments the best modification was chosen. It implies additional buoyancy module which is aimed to reduce vortex shedding.

2. 2D simulations

We used two-dimensional CFD model and Ansys Fluent code to simulate the flow over stationary gate section. Mesh sizes for considered cases were within two ranges: 200-250k cells for problems with turbulence modeled and 800-900k cells for cases without turbulence model. The computational area and boundary conditions are shown in Figure 4. It involves the areas filled with water (blue) and air (light blue) as well as gate cross section. The Reynolds averaged Navier-Stokes equations were numerically solved with volume of fluid model and without turbulence model. Such approach allowed to obtain good vortex structure resolution and more realistic force behavior [2, 3].

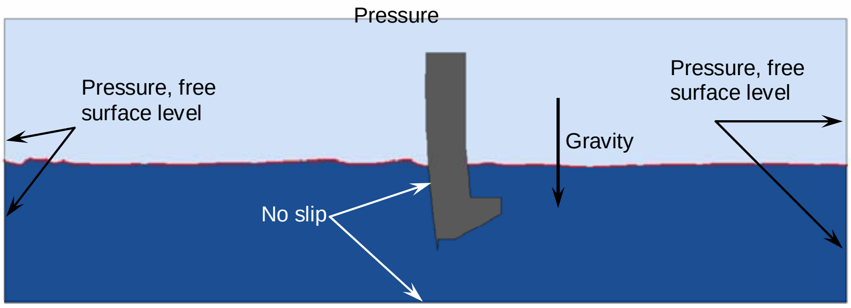

Figure 4 *Computation area and boundary conditions.*

Comparison of results for initial and revised constructions shows that the last one tends for smaller force oscillations. Amplitude of oscillations for initial construction is about 80000N and for revised 40000N (Figure 5)

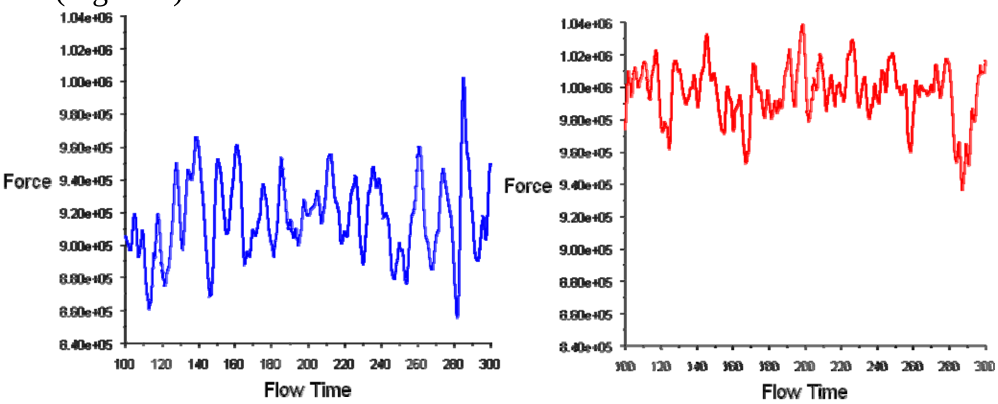

Figure 5 *Force vertical component oscillation (left – initial constr., right – revised).*11

At FFT diagram for old constructions clearly seen peak near eigenfrequency and no such peaks for modified construction (Figure 6).

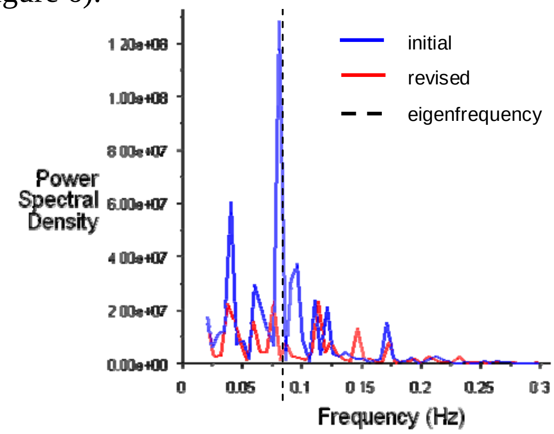

Figure 6 *Force vertical component, FFT.*

3. 3D simulations

Also 3D problem was considered and only for revised construction. The example of computational domain and boundary conditions are shown in Figure 7. The considered gate section is 30m in length and it corresponds to scale model from experiments. Dynamic Smagorinsky-Lilly LES turbulence model was used. Several cases were studied: three distances from bottom (2, 3, 10m) and two water level differences (1, 1.7m). Mesh sizes were 8.2-8.5M cells for most cases.

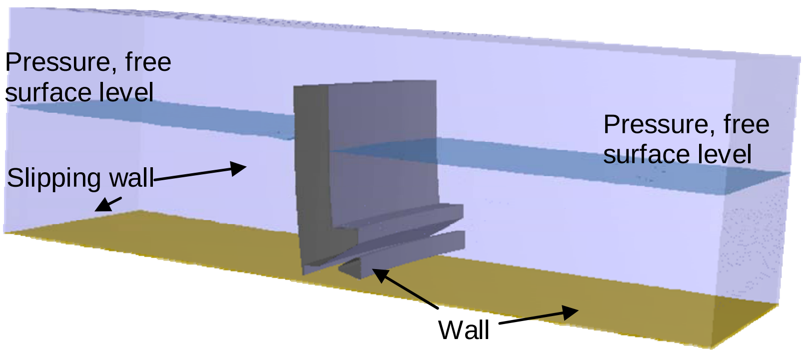

Figure 7 *Computation area and boundary conditions.*

For 2 and 3m distances from channel bottom the flow contained relatively small vortex structures while in case of 10m distance large scale vortex tubes were observed. Static pressure field without hydrostatic pressure at midsection and the isosurfaces of the same field are shown in Figures 8 and 9.

Figure 8 *Static pressure at domain's midsection and isosurfaces of pressure for 2m distance to bottom and 1m level difference.*

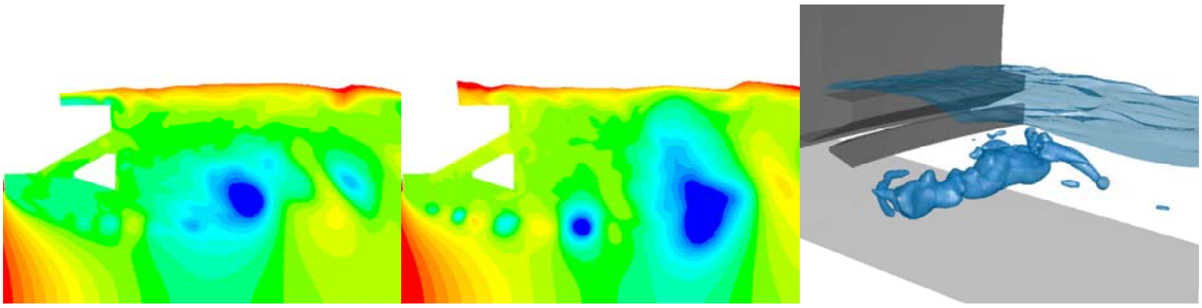

Figure 9 *Static pressure at domain's midsection and isosurfaces of pressure for 10m distance to bottom and 1.7m level difference.*

In cases of 2 and 3 m from bottom large period of force vertical component oscillation was observed. Depending on case the value of period varied in range from 40 to 55 seconds. For cases with 10m distance to channel bottom oscillations were completely different and did not have such a period. The examples of force oscillations and their FFT are shown on Figure 10.

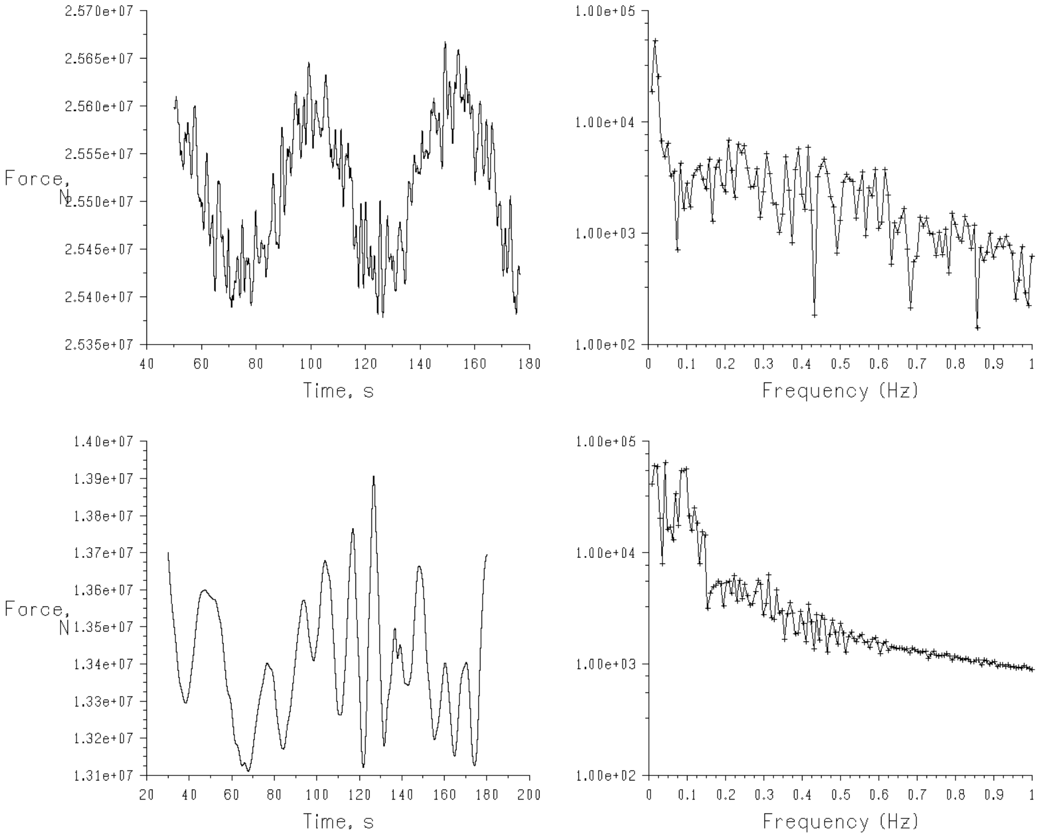

Figure 10 *Vertical force component (left) and corresponding FFT (right) for cases 2m-1.7m (upper) and 10m-1m (lower).*

To investigate dependence of obtained solution from domain size, the case with extended domain was considered (region after gates was extended from 50m to 300m). As a result, the force oscillation became more complicated – 50 second period oscillation superimposed on lower frequency oscillations. Also case with different boundary conditions was considered – at domain inlet mass flow rate condition was applied. In this case the shape of force vertical component oscillation also has changed. The dependence from time does not contain 50 sec. period, but tends to greater period – about 200 seconds.

4. Comparison with physical experiments

Gates system designers are interested not only in force oscillation but also in some constant force component, which is the difference between mean force value and Archimedean force. Comparison of results of numerical simulation and physical experiments is shown in Figure 11. In this work Archimedean force was calculated at still water: domain's inlet and outlet were set as walls and a wall was placed under gates to prevent flow.

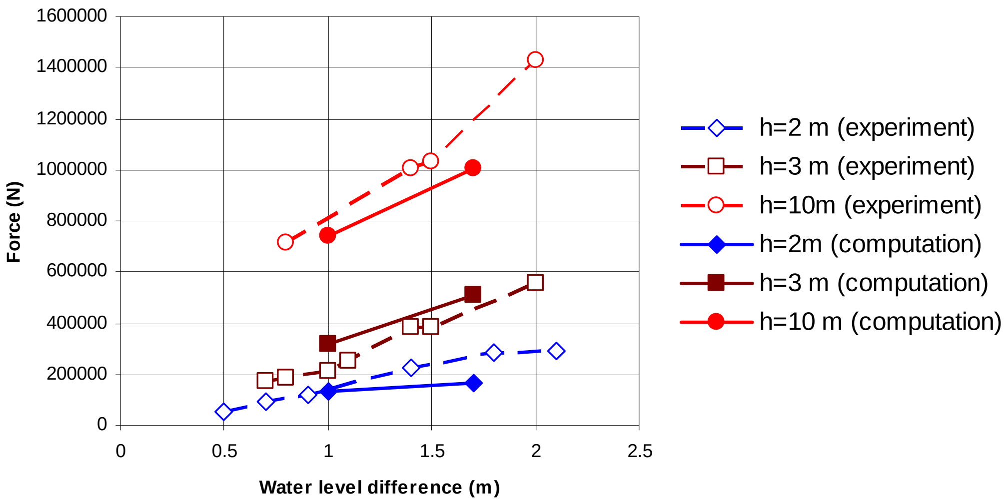

Figure 11 *Vertical force constant component, comparison with physical experiments results.*

5. Summary and further research avenues

Obtained results of numerical simulation of flow around gate section are in good correspondence with experimental data, both qualitatively and quantitatively. Several cases are still under study – especially investigation of solution's dependency from boundary conditions.

In further work studying of construction's free oscillations is planned. Experiments have shown difference between two approaches – flow around stationary gates and flow around moving gates. So the methodology for such simulations should be developed.

References

[1] Boldyrev, Yu., Lupuleac, S., Zhelezhyakova, O., *Numerical simulation of the turbulent flow in the dam ship passing channel*. In proceedings of the conference Innovations and technical policy,St. Petersburg, Russia, 2004.

[2] Petukhov E., *The simulation of the Saint Petersburg flood defense system gate vibration under the loads from the moving water*, Joint Advanced Student School, Saint-Petersburg – Munich, 2008.

[3] S. Lupuleac, A. Bol'shev, J. Shinder, E. Petukhov, V. Chernetsov, *The simulation of the Saint Petersburg flood defense system gate vibration under the loads from the moving water*, 9th International Conference on Flow-Induced Vibrations FIV2008, 30.06–3.07 2008, Prague, Czech Republic, 2008.