ISSN 0554-6397
Originalni znanstveni članak
(*Original scientific paper*)

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Numerical Simulation of River Inflows in Rijeka Bay Coastal Area

Abstract

In this paper, a model of water flow in the Porto Baroš has been developed, which is the part of the Rijeka coastal area, for the purpose of its renovation and conversion. For numerical simulation purposes, the depth of the seabed of Port was previously performed, based on which the geometry and numerical domain of Port were made. By conducting the flow simulation, the analysis was carried out, after which the analyses of the conceptual solutions with the introduction of the pipe discharge were performed with the aim of reducing the water pollution of the Porto Baroš area. **Port geometry will be made in commercial SMS software and numerical domains and simulations in OpenFOAM open-source software.**

Keywords: coastal flow, 3D numerical model, VOF, Rijeka port

1. Introduction

Due to a conceptual solution (from an urban development project) where the Rječina river in the city of Rijeka is connected to the Mrtvi Kanal channel for the purpose of cleansing it due to an increased amount of sedimented biological waste, a need to further analyze the flow of said waste and water is necessary. After the Mrtvi Kanal channel, the water flow is directed towards the enclosed port of Porto Baroš which is of central interest in this paper.

In order to predict the transport of sedimentation, it is important to know the vortex dynamics of Porto Baroš. An analysis of different river inflows of 5, 35 and 70 m^3/s into Porto Baroš was conducted. The conducted numerical analysis includes sediment transport. An additional analysis was done that includes conceptual solutions of the introduction of pipe discharges in order to eliminate the adverse impacts of river water flow to the Port area.

Computational fluid dynamics (CFD) methods were used to analyze the flow dynamics of Porto Baroš. CFD is an important tool in modeling coastal flow and popular coastal flow CFD solvers include software like SCHISM [1], FVCOM [2] and ADCIRC [3]. In this paper, the open-source CFD toolbox OpenFOAM [4] was used. OpenFOAM is a library of CFD solvers and for this purpose, two multiphase solvers were used, interFoam for the conceptual solution which includes pipe discharges and multiphaseInterFoam for the sediment transport. The seabed terrain of Porto Baroš was measured and the measured points were interpolated to form a surface. Additionally, the obtained surface was extruded to form a 3D geometry.

2. Material and Methods

2.1 Geometry creation

For the purpose of creating the geometry of the Port Baroš port area, the depth of the seabed at individual port points was previously measured. The mean depth of the seabed, at previously measured points, was calculated with the help of mareographic data obtained from the Geophysical Institute of the Faculty of Science at the University of Zagreb. Using the above information, a numerical grid of the seabed 3D surface was generated in the SMS software as shown in Figure 1..

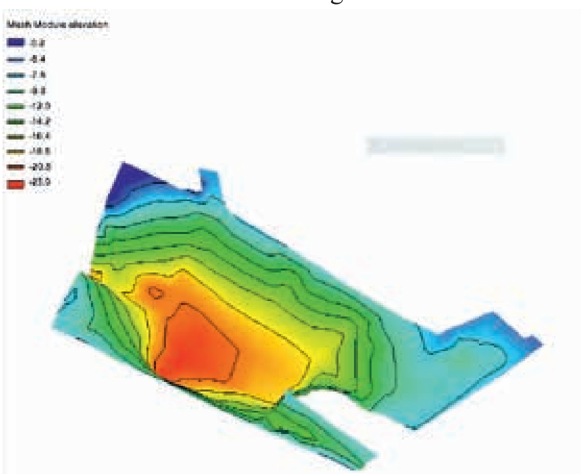

Figure 1: Seabed surface structure

Edges are defined at the border of the surface, as shown in Figure 2. By extruding the edges, the remaining surfaces that surround the domain are obtained. Figure 3. shows the 3D surfaces of the Porto Baroš domain while Figure 4. shows the generated numerical mesh of the Porto Baroš area.

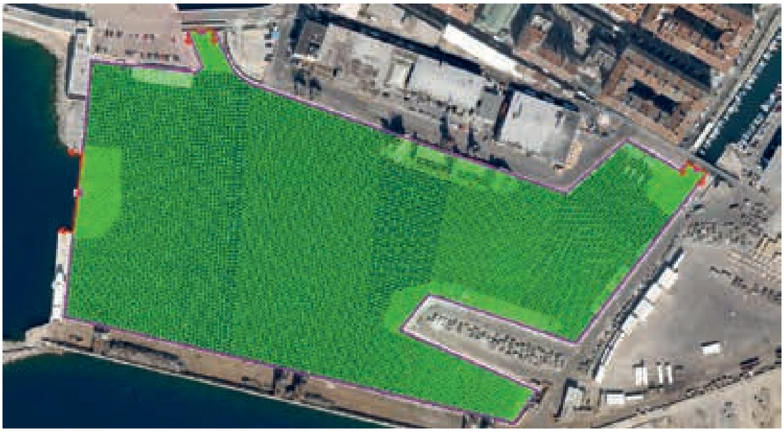

Figure 2: Edges of the surface of Porto Baroš

Figure 3: 3D model of the domain

Figure 4: Numerical mesh

2.2. Numerical simulation

Numerical simulation was performed in OpenFOAM which is based on the finite volume method to solve the partial differential equations of fluid flow. The multiphase OpenFOAM solver interFoam was used to model the described problem of adding pipe outflows to the domain, while the sediment transport problem was solved using the multiphaseInterFoam.

The isothermal, incompressible 3D Navier-Stokes equations were solved coupled with the phase equation of the Volume-Of-Fluid method. The interFoam includes two immiscible phases (air and water) while the multiphaseInterFoam includes three immiscible phases (air, water, and sediment). The Navier-Stokes equations are averaged to model turbulence with the k-Omega turbulence model.

In the VOF method, the transport equation of a phase is solved. The volume fraction α which represents a phase takes on values in the range , where indicates that there is only 1 phase in the finite volume cell and another phase for $\alpha = 1$. If the value is in between those limits, a mixture of phases is occupying the cell.

$$\rho = \alpha\rho_l + (1-\alpha)\rho g \tag{1}$$

$$\frac{\partial\alpha}{\partial t} + (\alpha u) + \nabla(\alpha(1-\alpha)u_r = 0 \tag{2}$$

where ρ_1 and ρ_g are the densities of fluid and air, respectively.

In the multiphaseInterFoam solver, a transport equation is solved for three phases and along with the air and water phase, a sediment phase (slurry) was included which had a density of 1124 kg/m³ and a viscosity of 1.38 m²/s. The initial distribution of phases (air and water) in the domain can be seen in Figure 5.

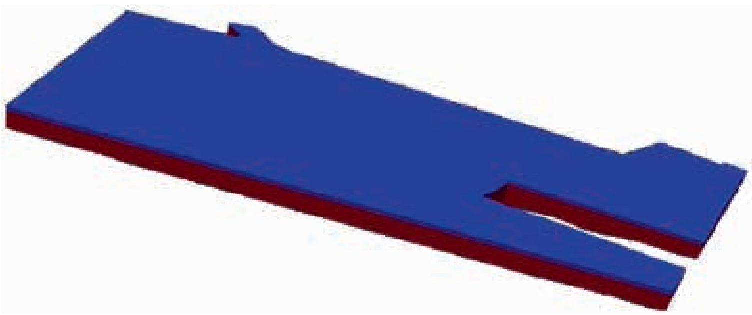

Figure 5: Distribution of water and air within the domain (red region is the water phase while blue is air)

The numerical simulation was done on a mesh with 2119325 elements on the Bura supercomputer at the Center for Advanced Computing and Modelling at the University of Rijeka.

3. Results and discussion

3.1. Flow with sedimentation

In Figure 6. the distribution of velocity the fields within domain at a water flow of 35 m^3/s can be seen, and Figure 7. shows the velocity field at a water inflow of 70 m^3/s. When comparing the two figures, it can be observed that with both inflows a vortex structure is apparent but in the case with the higher inflow of 70 m^3/s, vortex stretching is much more prominent due to higher turbulence momentum.

In Figures 8. and 9. the sediment phase is shown and it can be seen that although the sedimentation is quite similar, the higher inflow spreads the slurry further with additional layers.

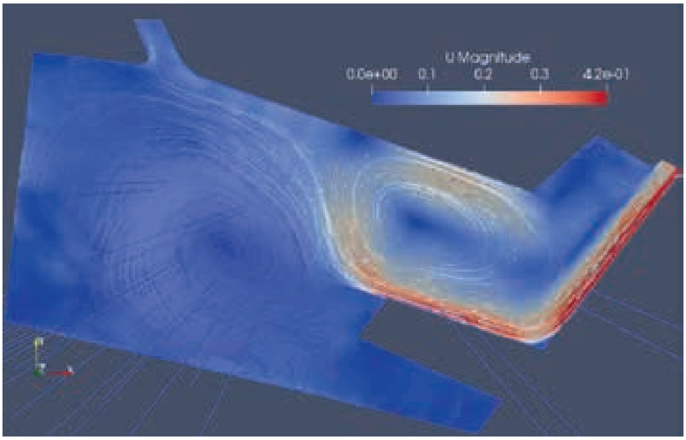

Figure 6: Velocity field at a flow rate of 35 m^3/s

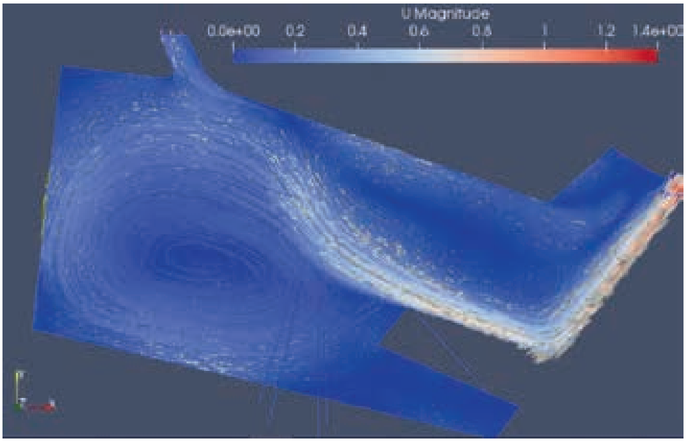

Figure 7: Velocity field at a flow rate of 70 m^3/s

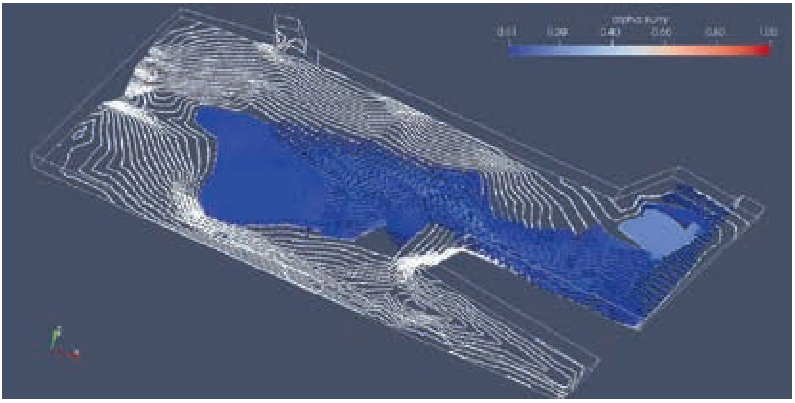

Figure 8: Sediment deposition area at a flow rate of 35 m³/s

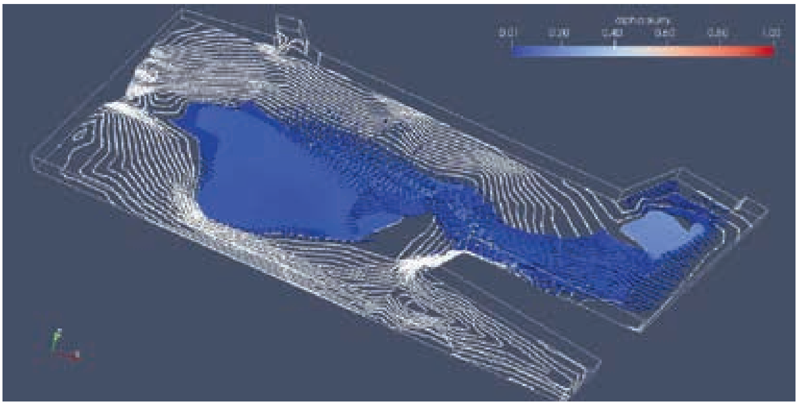

Figure 9: Sediment deposition area at a flow rate of 70 m³/s

From the above results, it can be concluded that in the case of introduction of river flows into the area of the port of Baraoš, vortices will occur in the central part and inlet part of the domain. Swirling will result in accumulation of impurities and sediment deposition.

3.2. Pipe outflow conceptual design

In order to increase the flow of water through the Port area, preliminary designs were proposed and analyzed with the addition of 2 m diameter pipe outlets. Figure 10. shows the position of three pipe outlets of a conceptual design, and Figures 11. and 12. show the velocity field at flow rates of 35 m^3/s and 70 m^3/s at the proposed conceptual design.

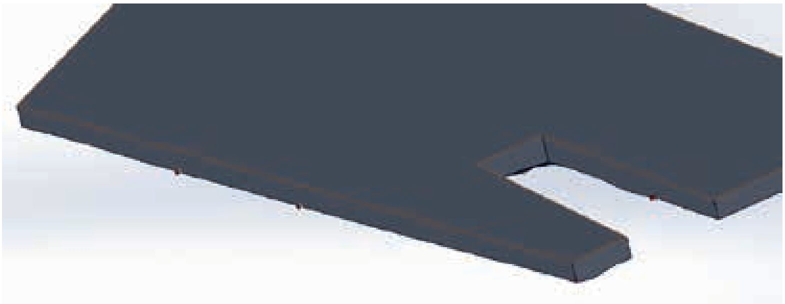

Figure 10: Conceptual design with three pipe outlets

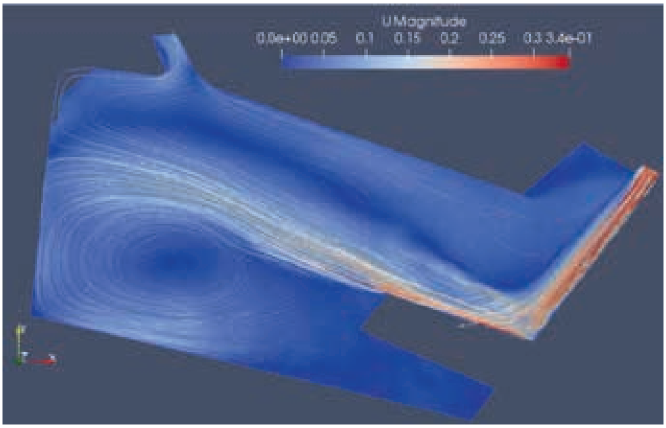

Figure 11: Velocity field at a flow rate of 35 m^3/s

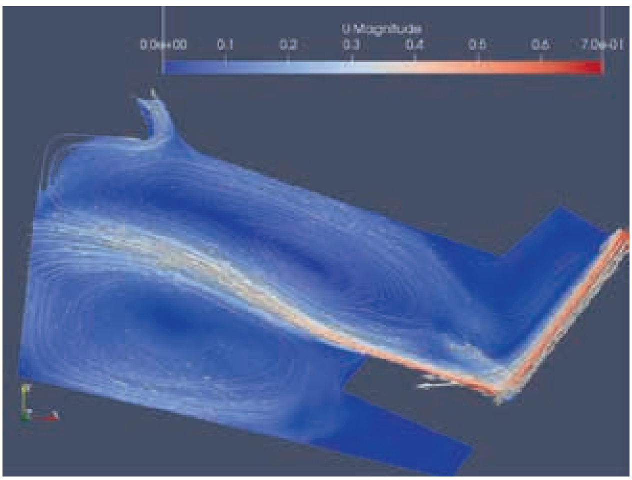

Figure 12: Velocity field at a flow rate of 70 m^3/s

It can be seen in the presented results that this solution does not have a satisfactory effect on the flow of water through the domain due to the relatively small dimensions of the pipe outlets relative to the entire Port area. As the cost of realizing the introduction of discharges increases exponentially with increasing dimensions, we can conclude that the addition of discharges does not provide an adequate solution in reducing the water pollution of the Porto Baroš area.

4. Conclusion

The aim of this paper was to analyze the design idea of connecting the Rjecina river to the Mrtvi Kanal channel by means of a discharge pipe and the consequences of such a project on the coastal marine area. The reason behind this idea is that by redirecting the flow to the Dead Channel, it would decrease water pollution, bacteria, and odors.

In this paper, seafloor data was collected, based on which the geometry and numerical domain of the Porto Baroš port area was made. By conducting fluid flow simulations in the Port area, velocity and pressure fields were analyzed, locations of vorticity occurrences were determined and expected areas with higher sediment deposition and the increase of pollution concentration were determined.

After analyzing the results, a conceptual solution was offered, aimed at reducing the vorticity and increasing the flow of water within the domain. Numerical simulations have shown that the proposed conceptual design with discharges do not contribute to a significant outflow of water mass from the port of Porto Baroš or contribute to the reduction of potential contamination within the domain.

The 3D VOF flow models have been successfully applied in the paper to analyze the irregular realistic geometry of the coastal area and thus obtain accurate flow fields.

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