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Master Thesis

3D Numerical Simulation of the Hydraulic Capacity of Overflow Sections on the Danube

Submitted by

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Abstract

Overflow sections are common along the Danube in Austria, enabling controlled overflow in regions with low damage potential. Accurately approximating their hydraulic behavior is complex due to the discharge variability along the length of the overflow section. The object of this research is to determine whether a 3D numerical simulation with Ansys CFX is advantageous in this process. In the first part, a grid study is conducted with terrain data of a study site at an overflow section of the Danube in the Machland region. Multiple terrain-based grids are created, evaluated and a workflow is established. Tetrahedron element grids turned out to be more advantageous in accurately depicting the terrain surface and could be created in a comparatively automized manner. Hexahedron elements were more advantageous for examining the hydraulic behavior, which lead to the closest approximations of the water surface and the shortest required simulation time. In the second part the model set-up is established by examining simplified geometric schematic geometries. The results of the 3D simulation show that the overtopping discharge is estimated to be lower than the 2D simulation results provided and values obtained using an engineer's equation. To conduct a final transient simulation four consecutive simulation set-ups are established to optimize the size of the computational domain and the simulation time. To conduct a 3D simulation of a large-scale river section of a flood event over a considerate time period, still requires substantial computing power and time as well as extensive time resources for the grid generation and simulation set-up. The workflows developed can improve the time required for 3D simulation with grids based on terrain data and on establishing simulation set-ups to solve questions in river modelling with Ansys CFX.

Kurzfassung

Überströmstrecken sind entlang der Donau in Österreich weit verbreitet, sie ermöglichen ein kontrolliertes Überströmen des Flusses in Regionen mit geringem Schadenspotential. Eine genaue Approximation des hydraulischen Verhaltens ist komplex aufgrund der Abflussvariabilität über die Länge der Überlaufstrecke. Das Ziel der Arbeit ist es, mögliche Vorteile einer 3D numerischen Simulation zur Analyse des hydraulischen Verhaltens mittels Ansys CFX zu evaluieren. Im ersten Teil der Arbeit wird eine Gitterstudie durchgeführt, die Gitter basieren auf Geländedaten des Untersuchungsgebietes an einer Überströmstrecke der Donau im Machland. Mehrere geländebasierte Gitter werden erstellt, evaluiert und die Arbeitsabläufe festgelegt. Gitter mit Tetraederelementen erwiesen sich als vorteilhafter für die genaue Darstellung der Geländeoberfläche und konnten vergleichsweise automatisierter erstellt werden. Für die Untersuchung des hydraulischen Verhaltens erwiesen sich Hexaederelemente als vorteilhafter, da die Wasseroberfläche am besten approximiert werden konnte und die kürzeste Simulationszeit benötigt wird. Im zweiten Teil wird der Modellaufbau durch die Untersuchung vereinfachter geometrischer Schemata festgelegt. Die Ergebnisse der 3D-Simulation zeigen einen geringeren überströmenden Abfluss gegenüber einer 2D-Simulation und einer ingenieurmäßigen Berechnung. Zur Durchführung einer abschließenden transienten Simulation werden vier aufeinander folgende Simulationsaufbauten erstellt, um die Gittergröße und die Simulationszeit zu optimieren. Die Durchführung einer 3D-Simulation eines Hochwasserereignisses über einen großen Fließgewässerabschnitt erfordert erheblich Rechenleistung und Zeitressourcen für die Gittererstellung wie auch für den Simulationsaufbau. Die entwickelten Arbeitsabläufe können genutzt werden, um die benötigte Zeit für die Gittererstellung und den Simulationsaufbau für Fragestellungen der Fließgewässerforschung mit Ansys CFX zu verbessern.

9. Conclusions and Outlook

The aim of the thesis is to examine the hydraulic capacity of overflow sections by conducting 3D numerical simulations. There is an increasing number of academic studies performed on the basis of 3D simulations to analyze the overflow behavior of side weirs which is similar to the flow over an overflow section. There are advantages in 3D simulations since, in principle, all flow phenomena can be modelled. Some situations as, for example, dam breaks which are not captured with simulations of lower dimensionality, can be modelled in a 3D simulation.

In the first part multiple options for grid generation and simulation set up are explored and evaluated. After examining multiple workflows to optimize the grid generation based on large scale terrain data for a simulation with Ansys CFX, a workflow for the grid generation is established. A fluid volume grid is generated from the terrain surface information either by creating a fluid volume geometry which is turned into a fluid volume grid or by creating a surface grid which is extruded into a volume grid. The creation of the fluid volume turns out to be time consuming and should be optimized further. Further possibilities include executing more steps in the GIS or grid generation software or employing alternative CAD software. The CAD and grid generation software packages used, except for Ansys Fluent Meshing, are not adapted to handling spatially varied large-scale data in a time efficient manner.

Tetrahedrons appear advantageous for the grid generation based on terrain data in an automatized manner while closely representing the terrain surface. However, it was not possible to create a tetrahedron grid enabling an adequate analysis of the flow situation evaluated. The prism grid provides a good balance between creation and computation time. However, it was not possible with the prism grid to achieve a sufficient approximation of the water surface close the embankment where it is most essential for examining the hydraulic situation. Ultimately, the hexahedron grid was the most advantageous for modelling the river channel domain. It enables the most exact approximation of the phase transition, while maintaining a low node count, thus leading to the shortest computational times and the lowest computing power.

There are studies which work with integrated terrain data in Ansys CFX. The integration of a small-scale grid-based on terrain data in Ansys CFX is possible without requiring extensive time resources. However, in this case the size of the computational domain is comparatively large. Moreover, the flood event takes place over a considerable time period.

In the second part the hydraulic capacity of overflow sections is examined on schematically simplified geometric channel geometries. The 3D simulations of schematic geometries required substantially less time resources in the grid creation, however still required considerable computational time and power. The simulation effort and result are however better balanced.

Overall, it can be concluded that the data of the 3D simulation predict that water starts to overtop the embankment earlier and that the overflowing volumes are comparatively higher for very low overtopping heights than the reference data indicated. A pre-study on the grid dependency was conducted to determine the optimum grid size to predict the water surface and flow parameters accurately with minimum computational time. The grid resolution is chosen to enable a transient simulation with the given computational power in an adequate time frame while providing a good approximation of the hydraulic situation studied. However, a higher grid resolution for the schematic channel could be beneficial. The overflow into the floodplain appears accurately approximated with the 3D simulation compared to the available measurement data in the middle of the time frame considered.

In the 3D simulation, the slope is less steep (time- discharge, overtopping height- discharge) which is due to a lower estimation of the overtopping water volume towards the end of the simulation time compared to the reference data. The roughness coefficient should be validated in more detail. The roughness parameter was not spatially varied over the river channel domain, instead a constant roughness was assumed. The flow situation at the boundaries of the volume grid is estimated based on the water level and discharge measurements from the gauging stations. No measurements on downstream water levels are available. For a more detailed study a closer examination of the boundary conditions with more extensive measurement data seems beneficial.

Including the surrounding area in the flow analyses can offer additional information on the spatial distribution patterns of the flow. This, however, requires larger computational domains. This raises the question whether the additional information obtained is worth the greatly increased computational time and resources.

10. Summary

Overflow sections are a substantial part of flood mitigation systems, enabling controlled overflow in regions with low damage potential. By pro-actively enabling overflow once the design discharge is exceeded, these sections protect the embankment from breaking. In line with the EU Floods Directive and integrative flood risk management, non-structural measures like floodplains are utilized here in combination with structural ones. For this purpose, it is important to determine the potential retention and its variability.

Overflow sections enable exchange processes in pre-designated areas instead of further enclosing the river which would increase the flood potential downstream. Overflow sections are common along the Danube in Austria. It is essential to flood water management to both be able to estimate the flow overtopping the overflow section and be able to predict the flow situation occurring in the case of a flood event. The complex flow situation due to the lateral spatially varied overflow can be closely approximated with a 3D numerical simulation in which no further simplifications of the equations of fluid motion are applied.

The objective of this thesis is to examine the hydraulic capacity of overflow sections with 3D numerical simulations. The research consists of two parts.

In the first part a grid study is conducted, and a workflow is established to create a grid based on terrain data for simulations with Ansys CFX. The terrain data of the overflow section from river kilometer 2105.2 – 2104 of the Danube before the hydropower plant Wallsee-Mitterkirchen in the Machland region has been chosen as a study site.

To create the fluid volume grid from the terrain surface data, either a fluid volume geometry is created from which a fluid volume grid is generated, or a surface grid is extruded into a volume grid. The creation of the fluid volume turned out to be time consuming when working with large scale data using the software employed.

Multiple grids based on different element types are examined, determining the time resources required for the grid generation and simulation, as well as evaluating the approximation of the relevant flow parameters. Tetrahedron grids are the most time efficient in the creation and approximate the terrain surface closely. However, a hexahedron element grid allows for the close approximation of the phase transition at the water surface which is advantageous for examining the hydraulic behavior as well as requiring the least computational time.

The second part is devoted to evaluating how the hydraulic capacity of overflow sections can be studied by 3D numerical simulations with Ansys CFX by comparing simplified geometric channel geometries.

The results of the simulation with the schematic 3D grid estimate a lower discharge overtopping the embankment than either available 2D simulation results or an empirical calculation of the overflowing discharge. Further research would be interesting when more data on the hydraulic situation are available, for example through physical experiments. Additionally, closer consideration and validation of the roughness factor and simulations with finer grid resolutions are advisable.

After carrying out simplified pre-studies, four consecutive simulation set-ups are established to conduct a transient simulation with a manageable computational domain size and simulation time. The prior simulations are employed to optimize the set-up of initial and boundary conditions.

Information on the spatial distribution patterns can be gained by including the floodplain in the simulation.

The 3D numerical simulation with a large computational domain over the considerable time frame of a flood event requires substantial computing power and time resources for the grid generation and the simulation set-up. The knowledge acquired on possible workflows can reduce the time resources required for the grid generation based on terrain data and on establishing a simulation set-up with Ansys CFX for addressing challenges in river modelling.