Use of CFD for optimization of hydraulic structures and hydropower plants

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***Abstract* – This article deals with new possibilities of using mathematical modelling for optimization in the field of hydraulic engineering elements. Optimization allows to increase the performance of structures while reducing investment costs. An interesting area is the shape optimization of hydropower plant structural elements. Demonstrations of the use of CFD will also cover the area of design of custom hydro turbines.**

***Keywords* – CFD, hydraulic structures, optimization, hydropower**

I. Introduction

In recent years, advancements in hardware performance have driven significant progress in CFD optimizations. While these optimizations are predominantly applied in mechanical engineering sectors such as turbines, aircraft, and ships, the field of hydraulic structures has lagged in adopting modern approaches. This disparity arises from the unique challenges and problems inherent to hydraulic engineering. Hydraulic structures are highly diverse and often atypical, featuring a wide range of water flow regimes. Consequently, they require bespoke solutions, as mass production is virtually non-existent in this field.

to create these components, incorporating the applicable criteria that follow.

II. CFD for optimization of hydraulic structures

Optimization of hydraulic structures is often constrained by the complexity and scope of computational tasks, as well as the demand for high accuracy, especially given the large dimensions of these structures. To maximize computational efficiency while maintaining sufficient accuracy and credibility, it is essential to simplify tasks as much as possible. Additionally, due to the scale of the structures, it is often necessary to limit the number of parameters describing their shape. This involves performing a sensitivity analysis to evaluate the impact of various parameters on the target objective function, allowing for the exclusion of parameters with minimal relevance before proceeding with optimization.

For instance, in the optimization of emergency spillways, bottom outlets, weirs, and navigation locks, it is often necessary to limit the number of parameters describing their shape. This involves performing a sensitivity analysis to evaluate the impact of various parameters on the target objective function, allowing for

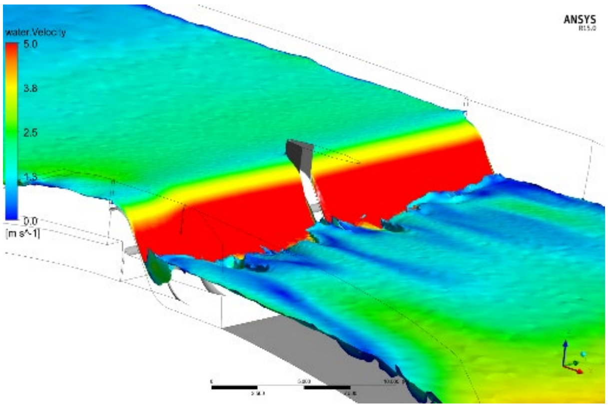

Figure 1. Klabava emergency overspill

Thanks to the CFD model we can obtain the exact water levels, velocities, tangential stresses, loads on given parts of hydraulic structures, under-pressure for cavitation assessment etc.

At the same time, it is advisable to examine the basic parameters of the spillway, especially the rating curves, i.e. the relationship between the elevation of the head water and the flow rate.

The optimization of hydraulic structures can be evaluated based on various criteria, such as the complexity of their shapes (standard, atypical, combinations, etc.) and the type of flow (steady vs. unsteady, single-phase vs. two-phase, etc.). A crucial aspect for practical applications is the economic benefits, which can be categorized into three types.

The first type involves revenue-enhancing optimizations of the design, such as intake structures of hydroelectric power plants (HPPs). The second type focuses on designs that reduce financial costs without direct financial returns, like the capacity of a spillway. The third type aims to meet specific construction criteria, such as optimizing the shape of the outflow section of an HPP to limit velocities and ensure safe navigation.

The increasing use of spatial models of structures, enriched with additional information (e.g., Building Information Modeling - BIM), and the growing integration of numerical flow modeling in the design of large water structures, contribute to reducing the overall cost of the optimization process. We anticipate that, with the advancement of these techniques, there will be a gradual and more widespread adoption of optimization processes in the field of hydraulic structure optimization.

III. CFD FOR HYDROPOWER

CFD plays a very important role especially in the hydropower industry. Shape optimization of structures can result in reduced hydraulic losses, improved turbine inflow conditions. Increased homogeneity of the velocity field, reduced turbulence and pressure pulsations will translate into increased turbine efficiency, calming the operation of the entire system while extending the lifetime of a very expensive piece of equipment.

On the Odra River near Ratowice, Poland, the construction of the Ratowice SHPP on the right bank above the weir and the left-bank branch of the navigation canal is planned. The study aims to evaluate the suitability of two original variants of intake structures in terms of hydraulic losses and terms of homogeneity of the velocity field in front of fine trash racks. Another task is to identify areas that will pose a risk for sediment deposition. The variant was assessed by CFD analysis.

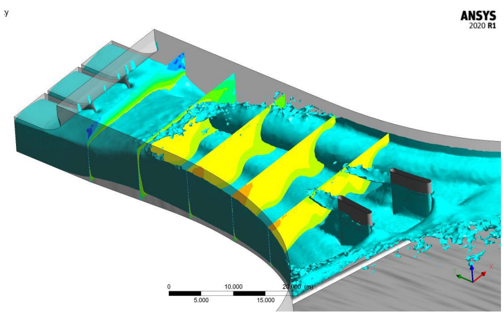

Figure 2. Example of low head HPP intake simulation

Based on the evaluation of two initially proposed variants, a third - compromise variant was subsequently presented. A total of 6 simulations were performed on three shape models of inlet objects. Concerning hydraulic losses, the most advantageous is the newly designed model III, which is also the shortest and, concerning the length of vertical structures, the least investment intensive.

A practical demonstration shows optimization of the hydraulic design process of the whole turbine and shape optimization of blades. The fully parametric model of the entire turbine was created by CAESES ® software. After sensitivity analysis, the main hydraulic shape of the turbine was fixed. Free parameters include those describing the shape of guide vanes and runner blades and their mutual position.

The hydraulic performance of the turbine is evaluated based on flow simulation in CFD software ANSYS CFX® with the use of structured grids created in ANSYS TurboGrid®. For quick decision making, we use a stationary flow model calculation of components or a flow model of the whole turbine. The subjects of this evaluation are hydraulic efficiencies of turbine components and the whole turbine, cavitation characteristics and alternatively, additional parameters, e.g. the forces and torque on guide vanes.

Sensitivity analysis showed the influence of single parameters on required hydraulic characteristics. In the case of guide blades, we tested the effect of shape parameters on the hydraulic efficiency and torque loading. As for the runner blade, we tested the effect of shape parameters on its hydraulic efficiency, cavitation, and turbine discharge. Hydraulic efficiency and cavitation properties were improved by the optimization cycle using the MOGA algorithm built-in Dakota module of CAESES®. The most suitable shape was chosen for subsequent testing.

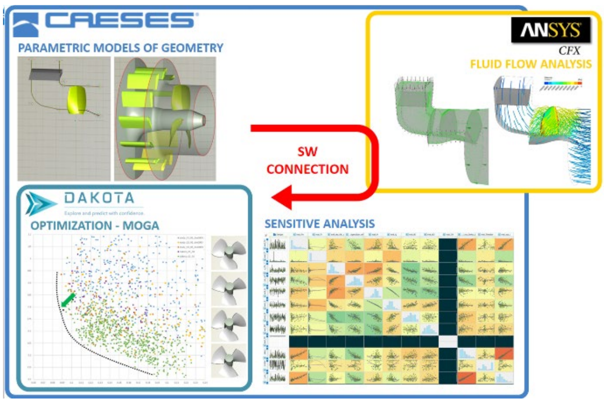

Figure 3. Workflow for automatic runner shape optimization

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