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COMPUTATIONAL MODELLING OF AN ESTUARY IN THE FRAME OF THE OPTIMISATION OF TIDAL FARMS

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ABSTRACT

Computational simulations are used in an increasing range of applications for coastal environments. Despite their advantages in comparison to other methods, there are still some uncertainties over the features involved, sometimes connected to the complexity of the large scale physical processes.
A 2D numerical simulation based on a Finite Volume Method (Mike21 by DHI) has been developed to study the hydrodynamic behaviour of the flow in the Solway Firth as a basis for the optimisation of tidal farms. The aim is to find a configuration with the maximum energy extraction and the minimum impact on flood risk. The boundary conditions applied in the model consisted of the highest tides and a storm surge. The results for the maximum water levels and velocities identified the areas with high risk of flooding and the potential locations for the tidal farms, respectively.
Due to the lack of observed data for turbulence in the estuary, a sensitivity analysis has been carried out to determine how the hydrodynamic results would be affected by this parameter. Regarding the integration of turbines in the estuarine model, results from a detailed 3D Computational Fluid Dynamics (OpenFoam) model of individual turbines and groups of them are used to account for the interactions within the farm and with the surrounding environment. Different configurations of tidal farms will be included in the simulations and optimised by means of nature-inspired genetic algorithms and advanced methodologies, such as artificial neural networks.

Keywords: *CFD; FVM; Hydrodynamics; Optimisation;Turbines*

1. Introduction

Computational simulations are used increasingly in different applications for coastal environments, ranging from representations of the near-field effects of structures deployed in a certain location up to the far-field effects of marine energy extraction at ocean scales. The current study is focused on computational simulations related to the environmental interactions of tidal farms in estuaries. Although there are some advantages in the simulations in terms of the balance between accuracy of results and computational costs in comparison to other methods, like simplified analytic approaches or physical models, the connection between different scales (in this case, tidal farm and estuary) within the model results in a high complexity. This project integrates both scales with the aim of providing a better understanding of the effect of tidal farms in estuaries.

The current study is focused on the Solway Firth area, which is a highly energetic estuary located in the West coast of Great Britain, between England and Scotland. The purpose is to optimise the layout of tidal farms in terms of maximum energy extraction and minimum environmental impact. The latter is represented by the influence that turbines could have on the existing water levels in the area. Flood risk is preferred here to other environmental parameters, such as suspended sediment concentration or changes in the morphology of the seabed, because it can be directly assessed with the same model used to calculate the extracted power. On the other hand, the cost of damages caused by flooding is very important from a social perspective.

2. Methodology

In order to achieve the integration between the different scales involved in the study, two kinds of models have been used: a Computational Fluid Dynamics (CFD) model and a Finite Volume Method solver. The detailed three-dimensional (3D) CFD modelling will provide results about the interactions of turbines within the farm. On the other hand, the computational demand of the CFD is very high to be used directly in the optimisation process. Therefore, a 3D FVM model (Mike3 by DHI) with a lower computational time is being compared with the CFD in the same cases. These models will be a basis for the optimisation of the energy output in the scale of the farm. In relation to the estuary, a 2D FVM system (Mike21 by DHI) has been used to assess the flood risk in the situation without turbines and these results will be compared with the cases including the optimised configurations of tidal farms. Finally, the comparisons will be used to find the solution which minimises the flood risk in the estuary.

3. Turbines and tidal farms modelling

CFD models have been developed to provide detailed information about wake formation and interactions between turbines. In this project the design of the turbines is based on the horizontal transverse flow type called Momentum Reversal Lift turbine, as can be seen from figure 1. Several situations have been performed in OpenFOAM, including individual turbines and groups of them [5, 6, 7, 8]. Currently, a model is being created to represent a group of thirty turbines in two different configurations, related to the experimental testing that will be carried out in the Allwaters tank in order to validate the results of the CFD models. The Allwaters facility is a curved tank located in the University of Edinburgh with the ability of recreating currents in any direction and situations with waves and currents at the same time. [11]

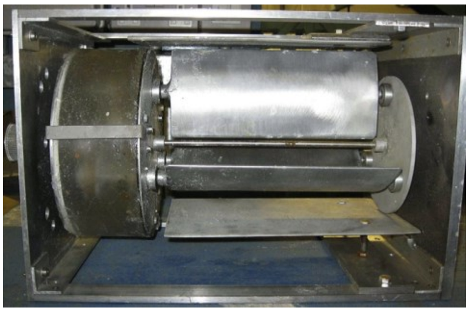

Figure 1: MRL turbine

In order to compare the aforementioned models with an application which can gives similar results with a reduced computational demand, Mike3 models have been developed consisting of three vertical layers. The central layer is referred to the turbine position and the upper and lower layers are related to the by-pass flows, according to the Linear Momentum Actuator Disk Theory, which allows studying the losses from turbulent wake mixing [4].

4. Estuary modelling

A numerical model of the Solway Firth Estuary has been defined by means of Mike21. The domain of the model is delimited by the inland boundary to the North-East, close to convergence of the rivers Esk and Eden, and by the open sea boundary at the South-West, between Head Abbey (Kirckcudbright Bay) and St Bee’s Head (Workington). The domain is covered by an unstructured flexible mesh created through the interpolation of bathymetry and terrain data. The former were obtained from the Celtic Seas dataset, provided by the British Oceanographic Data Centre [2], with a resolution of 30 arc seconds and 1 arc minute for the latitude and longitude, respectively. The terrain in the coastline was included between the shoreline and the 10 m elevation isoline and it was represented by points from the Profile Contour dataset, provided by the Ordnance Survey, with a vertical resolution between 5 and 10 m. The domain was divided in several subdomains with different refinements according to the areas where a higher accuracy was necessary

The duration of the preliminary simulation consisted of four tidal cycles and it was referred to an extreme scenario based on the 1 in 200 years return period event for the highest tide plus the atmospheric surge. The water elevations for this event were calculated following the guidance of the Environment Agency for the design of flood defences presented by McMillan et al. [1] and the data from the Admiralty Tide Tables 2013 and included as a boundary condition in the open sea boundary. Wind data have been obtained from Carlisle airport.

The value of the bed resistance was set to a constant value of the Manning's roughness coefficient according to the existing sediments in the seabed and varying according to Land Cover values in the Coastline, taken in ArcGis format from the UK Land Cover Map (LCM2007)**.** The land cover indexes were converted into Manning's roughness coefficients for natural floodplains. Due to the lack of data about turbulence in this area, a sensitivity analysis was carried out and the results showed that there was little influence of this parameter on the results. Therefore, a value of 0.28 for the Smagorinsky coefficient was adopted.

Figure 2 shows the results for the initial hydrodynamic model for the mean water levels and current velocities in the estuary. The maximum values give an idea about the areas at risk of flooding and the potential locations of tidal farms, respectively. These results are in good agreement with the information showed by the flood risk maps provided by the Environment Agency [3] and the Scottish Environment Protection Agency [10], as well as with the annual velocities from the UK atlas of marine renewable energy resources [12].

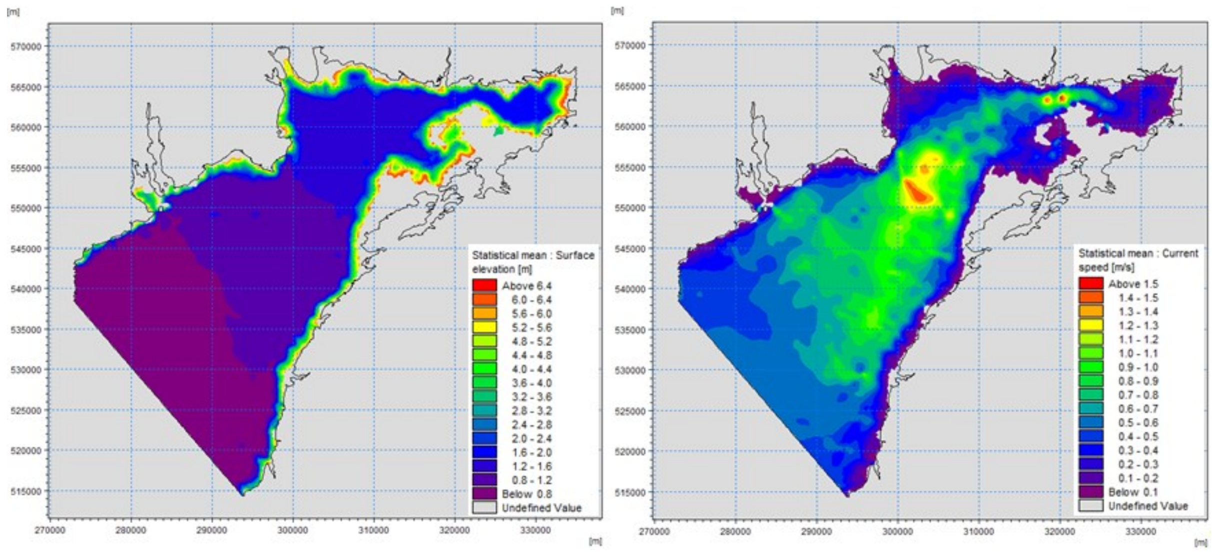

Figure 2: Mean water elevations and velocities from Mike21 model in the Solway Firth estuary, averaged over four tidal cycles.

The model has been calibrated according to the observed sea levels from the gauge station, with coordinates 54˚44.0'N and 3˚53.0' W, on 30th April 1977, being this dataset provided by the British Oceanographic Data Centre [2]. Data for the river flows on the previous date have been provided by the National River Flow Archive [9].

The model will include the main rivers along the boundary represented as sources. The peak flows for the 1:200 years return period are being obtained through the Environment Agency and the Scottish Environment Protection Agency. Further work will also include the evaluation, in terms of damages and monetary costs, and the comparison of flood risk levels from the model without and with the tidal farms in order to be introduced in next stages of the optimisation process. For that purpose the data about urban areas in the estuary are being collected.

5. Optimisation

Optimisation techniques based on genetic algorithms, will be applied to get the best configuration of tidal turbines within the farm in terms of the maximum power output. These configurations will then be included in the estuary model to assess the flood risk. Advanced techniques such as artificial neural networks will be used at this stage to improve the layout of the farm in order to have the minimum impact on flood risk.

6. Conclusions

Further work will focus on Mike3 models of individual turbines and groups of them and the comparison with OpenFOAM results, which are being validated through experimental testing. These models will be integrated in the optimisation process in order to determine the configuration that could extract maximum energy from the flow.

Results from the 2D estuarine model without tidal farms show good agreement with the official data sources and give an idea about the locations with high levels of flood risk and the potential locations for the tidal farms. Turbines will be included in a direct way as drag forces against the flow and the model will be used as a basis to provide the layout of the tidal farm with the minimum induced flood risk.

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References

[1] A. McMillan, C. Batstone, D. Worth, J. Tawn, K. Horsburgh, and M. Lawless, *Coastal flood boundary conditions for uk mainland and islands. project sc060064/tr2: Design sea levels*, 2011.

[2] *British oceanographic data centre*. http://www.bodc.ac.uk/. Accessed: 2014-01-28.

[3] *Environment agency*. http://www.renewables-atlas.info/. Accessed: 2014-01-28.

[4] G. Houlsby, S. Draper, M. Oldfield, et al., Application of linear momentum actuator disc theory to open channel flow, *Report no. OUEL*, vol. 2296, no. 08, 2008.

[5] M. Berry, CFD Analysis of a Single MRL Tidal Turbine, *Proceedings of the 2nd Oxford Tidal Energy Workshop*, pp.37-38, 2013.

[6] M.G. Gebreslassie, G.R. Tabor and M.R. Belmont , Cfd simulations for investigating the wake states of a new class of tidal turbine, *Journal of Renewable Energy and Power Quality*, 10(241), 2012

[7] M.G. Gebreslassie, G.R. Tabor and M.R. Belmont, Numerical simulation of a new type of cross flow tidal turbine using OpenFOAM Part I: Calibration of energy extraction, *Renewable Energy*, 50:994-1004, 2013

[8] M.G. Gebreslassie, G.R. Tabor and M.R. Belmont, Numerical simulation of a new type of cross flow tidal turbine using OpenFOAM Part II: Investigation of turbine-to-turbine interaction. *Renewable Energy*, 50:1005-1013, 2013

[9] *National river flow archive*, http://www.ceh.ac.uk/data/nrfa/data/search.html. Accessed: 2014-01-28.

[10] *Scottish environment protection agency*, http://www.sepa.org.uk/flooding.aspx. Accessed: 2014-01-28.

[11] T. Davey, I. Bryden, D. Ingram, A. Robinson, J. Sinfield, and A. Wallace, The all-waters test facility- a new resource for the marine energy sector, *Proceedings of the 4th International Conference on Ocean Energy,* Dublin, Ireland, 2012.

[12] *Uk atlas of marine renewable energy resources*, http://www.renewables-atlas.info/. Accessed: 2014-01-28.