The sensitivity of tidal resonance in the Bristol Channel

Chanshu Gao*, Thomas A. A. Adcock and Sena Serhadlıoğlu
Department of Engineering Science, University of Oxford, UK

Summary: The energy resource in the Bristol Channel is of national strategic significance to meet the future demand for low carbon energy, and is the single largest resource area for tidal energy in the UK. However, the complex tidal dynamics of the Bristol Channel are not yet fully understood, in particular the sensitivity of the tidal dynamics to changes such as those caused by energy extraction. This is the motivation for the development of a simplified two-dimensional model to simulate the tidal flows in Bristol Channel. The tidal resonance in Bristol Channel has been investigated by exciting the model with a single tidal component and a series of sensitivity tests have been carried out on tuneable model parameters.

Introduction

The semi-diurnal tides observed in the Bristol Channel are one of the largest in the world with a mean tidal range of 12.2 m at spring tides, which is driven by two main mechanisms: one is the funnelling effect at the upper reaches of the Bristol Channel due to its wedge-shaped geometry and shallow bathymetry; and the other is the quarter-wave length resonance of the Channel with the Atlantic tidal wave [1]. Resonant systems are typically very sensitive to small changes, but will be highly site dependent and further work is needed to fully understand them [2]. Therefore, a simplified two-dimensional model has been developed to investigate the resonances in Bristol Channel using the discontinuous Galerkin (DG) version of ADCIRC, which is a well-developed hydrodynamic finite element model. The DG-ADCIRC solver is capable of using highly flexible unstructured grids that are used to solve the governing equations for coastal and ocean circulations problems [3].

Methods

Fig. 1 shows the overall computational mesh with 16 selected observation stations (From ST1 to ST16) used to model the Bristol Channel. This unstructured grid allows a large variation in the scales of regions of interest, which in this study varies from 500m to 5000m. The open boundaries are forced with a single sinusoidal constituent with an amplitude distribution across the boundary given by that of the M_2 constituent interpolated from a larger model [1]. The DG-ADCIRC modelling parameters were set as constant throughout the study: most of the parameters were attained as the default values recommended by the ADCIRC model developers and used in Serhadlıoğlu *et al.* [4]; while the rest, such as time step, bottom friction, wetting and drying were determined using equations and a parameter sensitivity analysis for the area of focus. Four stations (ST3/5/7/9) were chosen to represent the inner section of the Channel while three stations (ST11/13/15) represent the outer Channel. Water level, nodal factor and bed friction parameters were chosen for the sensitivity tests.

Results

The response curves of the Bristol Channel have been investigated by exciting the model using artificially altered M_2 forcing frequencies (ω), and applying a ratio (ω/ω_{M2}) varying between 0.5175 and 5.175 (Fig. 2). All the stations show a peak in response at around a ratio of 1.2-1.4 which indicates the quarter-wave length resonance of the system with a period of approximately 8.6-10 hours. The inner section of the Bristol Channel (ST3/5/7/9) shows an amplified response over the frequency range ω/ω_{M2}ratio of 1.2-1.4 while the outer part of the Channel (ST11/13/15) exhibits an apparent resonance around the ratio of 3.1-3.6.

The results of the sensitivity test on water level, nodal factor and bed friction in both inner (ST5) and outer (ST11) parts of the Channel are shown in Fig. 3. The response tides are driven by natural frequency (ω/ω_{M2}=1). With water level varying from 4 m lower to 4 m higher than the real situation, the tidal heights do not present visible change. Over a period of 9.3 years, the M_2 nodal factor changes from its minimum (maximum) value, to its maximum (minimum); however, during this time period the M_2 tidal heights almost remain the same. The bed friction is seen to be a dominant effect on the tidal response, since the M_2 amplitude at ST11 decreases by around 0.2m with the quadratic friction coefficient increasing from 0.0025 to 0.005. The bed friction has even greater influence on the shallower areas: at ST5 the amplitude change reaches more than 0.3m.

* Chanshu Gao.
Email address: chanshu.gao@eng.ox.ac.uk

Conclusions

Preliminary studies show that the quarter-wavelength resonant period of the Bristol Channel is close to but shorter than the semi-diurnal tidal band, suggesting that the basin length of the Bristol Channel is shorter than the resonant quarter-wavelength. The response curve obtained in the study suggests that there is another resonance occurring in the Bristol Channel, which might be the resonant response of the Bristol Channel itself. The bed friction chosen has a significant effect on the response of the inner channel location when forced by an M_2 tide, which may have implications for tidal energy extraction. Neither the amplitude on the boundary, nor the mean water level, has a significant impact on the resonant response, suggesting that the nodal factor of the tide, or any possible sea-level rise, will not have a dramatic effect on tidal response in the Channel. Further investigation of the idealised 2-D model and consideration of the real situation of tidal dynamics in the Bristol Channel are necessary to take this analysis further.

References:

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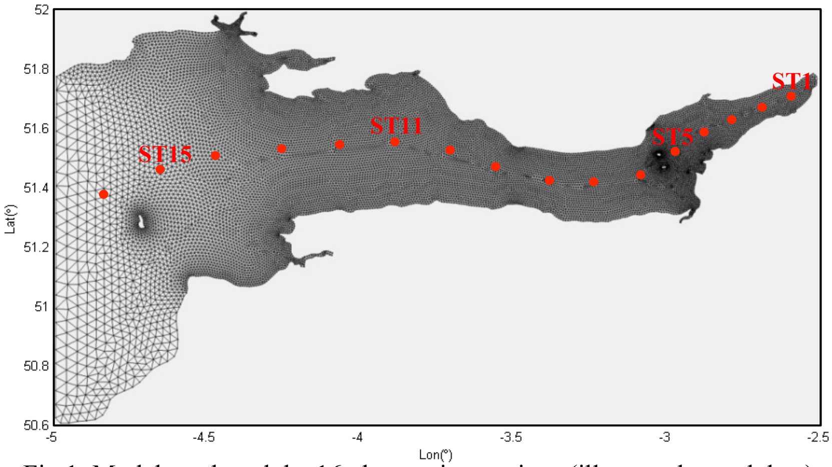
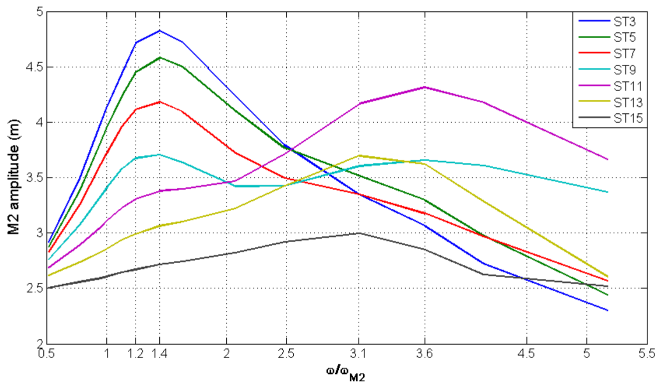


Fig.1. Model mesh and the 16 observation stations (illustrated as red dots).



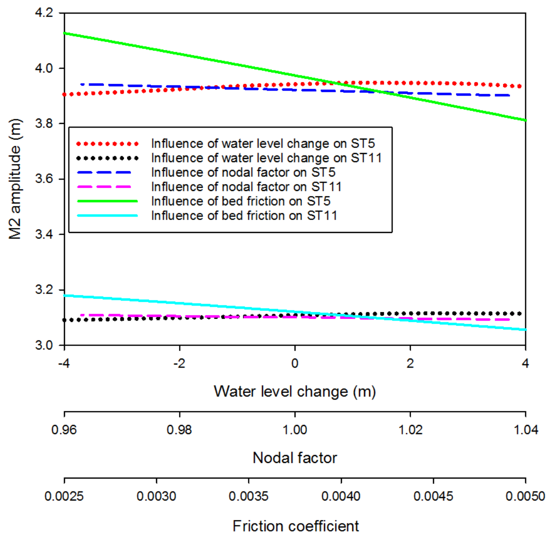


Fig.2. The response curves of several stations along the Bristol Channel: ST3, ST5, ST7 and ST9 represent the inner Channel response; ST11, ST11 and ST15 represent the outer Channel response.

Fig.3. Sensitivity test results on water level (dotted lines), nodal factor (dash lines) and bed friction (solid lines) at ST5 and ST11.