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Editorial

Numerical Investigation of Wave-Structure Interaction

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The simulation of the propagation and evolution of sea waves in coastal regions and their interaction with coastal structures is a very useful engineering tool in several problems of coastal and environmental engineering. The numerical studies of wave–structure interaction can be divided in two main categories: numerical studies in which the main goal is to simulate the motion and dynamic response of moving structures subjected to wave action, and numerical studies in which the main goal is to simulate the modifications produced on waves and wave-induced hydrodynamic fields by the presence of a fixed coastal structure. This Special Issue provides very interesting examples of both these main categories of numerical studies. Two of the papers of this Special Issue, [1,2], belong to the first category, as they concern the simulation of the interaction between wave motion and an energy converter and a floating bridge, respectively. The papers [3,4] belong to the second category, as they concern the simulation of modifications produced on a wave and hydrodynamic fields by the presence of a submerged and emerged coastal defence structure, respectively. The fifth paper, [5], concerns the proposal of a numerical procedure to improve the accuracy in studying the interactions between seismic waves and bottom sediments.

In the numerical studies of wave–structure interactions, several approaches can be used to simulate the wave motion and wave-induced flow velocity fields and the motion of the structure. These approaches usually range from the analytical one, in which the free-surface elevation, flow velocity fields, and external loads acting on the structure are calculated by analytical expressions, to the numerical approach, in which two-dimensional numerical models based on depth-averaged flow motion equations or three-dimensional numerical models based on the Navier–Stokes equations and equations of motion of the structure are adopted. Usually, the choices of the adopted approach and related numerical models depend on the spatial dimensions of the physical domain that has to be discretized, the duration of the phenomenon under investigation, and the expected accuracy of the numerical results. The papers compiled in this Special Issue provide examples of all three approaches: in [1,2], simulations of wave motion and wave-induced hydrodynamic fields that produce external loads are obtained by an analytical approach, while the motion of the structure is simulated with a three-dimensional numerical model; in [3,4], the simulation of the wave and hydrodynamic fields that interact with the coastal defence structures are carried out with a two-dimensional numerical model based on depth-averaged flow motion equations and a three-dimensional one based on the Navier–Stokes equations, respectively. In [5], an analysis of the seismic wave signals used to characterize the bottom sediments is carried out with an analytical approach accompanied by an iterative numerical procedure.

In [5], the goal of Mitrofanov et al. is to improve the accuracy in studying the interactions of seismic waves with bottom sediments in order to characterize them in terms of the quality level necessary to study the evolution of the seabed during short time intervals. The measurements of the spatial and temporal variations in seabed elevation and sediment characteristics can provide very important data for many engineering works, such as the design of coastal defence structures or sediment removal campaigns. In [5], it is shown that the use of a high-quality seismic system is a necessary but not sufficient condition to obtain high-quality data for the evaluation of seabed characteristics and elevation. The data

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obtained using high-quality marine surveys have significant variations in wavelets at all analysed frequencies. Part of these variations are related to the characteristic of excitation and reception of oscillations. As demonstrated in [5], using a method based on factor decomposition in the spectral domain and an iterative numerical procedure significantly reduces the changes associated with the sources and receivers of seismic signals, as well as improve the data quality of marine surveys, from hundreds of hertz to kilohertz.

In [1], Michailides proposes a numerical method for the analysis of the interaction between surface waves and floating structures designed to produce energy from waves. In this numerical method, the hydrodynamic coefficients used to evaluate the external load exerted by the wave motion are obtained by assuming simplified hydrodynamic fields given by the potential flow theory. This assumption makes it possible to avoid the simulation of the wave and hydrodynamic fields in the whole coastal area in which the floating structure is placed, with a significant reduction in computational costs. The main goal of the original method proposed in [1] is to overcome further simplifications usually adopted in the literature when the potential flow theory is adopted, according to which the viscous damping loads are considered constant in the wave–structure interaction problems. To this end, Michailides [1] proposed a numerical procedure based on a three-dimensional numerical simulation of the motion of the structure in the time domain and an iterative process, which is performed at every time step of the simulation, to take into account the velocity of the structure in the calculation of its viscous damping coefficients. In the model proposed by [1], the results obtained by the use of potential flow theory are used as input data for a three-dimensional numerical model carried out by a finite element method that numerically solves the equations of motion of the structure in the time domain. At every time step of the above solution, an original numerical analysis process calculates the velocity-dependent linear and quadratic viscous damping coefficients. This procedure requires the previous calculation of linear and quadratic viscous damping coefficients. In [1], the above coefficients are calculated by using free decay curves that are generated by numerically simulating the oscillations of the floating structure subjected to an initial displacement. Those numerical simulations are carried out by solving the three-dimensional Navier–Stokes equations on a computational grid that is slightly larger than the volume occupied by the floating structure. In this way, high-accuracy structural responses can be obtained with lower computational costs than those of numerical methods based on the three-dimensional simulation of the hydrodynamic fields around the structure (three-dimensional coupled fluid–structure interactions models).

In this Special Issue, another example of numerical study belonging to the same category of paper [1] is that proposed by Wan et al. [2], which concerns the numerical study of the dynamic response of curved floating bridges with a small rise–span ratio. The main goal of the paper is to evaluate the response and internal forces of horizontally curved floating bridges subjected to wave actions. For this type of numerical problem, the maximum accuracy is dedicated to the simulation of the dynamic response of the floating structure that is modelled using a finite element method, while the wave motion and flow velocity fields for the evaluation of the hydrodynamic properties of the structure are analytically calculated in the frequency domain by the use of potential flow theory. The calculated hydrodynamic properties are then transferred into the time domain, according to the so-called hybrid time and frequency domain method. Using this approach, the authors assume some simplifications in the hydrodynamic model in order to reduce the computational costs and maximize the accuracy of the structural response. The proposed methodology is applied to two different bridge lengths of 500 and 1000 m with the same rise–span ratio. The obtained numerical results show that bridges with different lengths have various response properties, and the short bridge provides a prominent arch effect compared to the long bridge, despite the same rise–span ratio being applied.

Papers [3,4] of this Special Issue belong to the second above-described category. Both papers are examples of wave–structure interaction numerical studies in which the simplification consisting of adopting the potential flow theory to approximate the wave fields and wave-induced hydrodynamic fields interacting with the structures is no longer acceptable. In [4], the main goal of the proposed numerical model is to simulate, in a fully three-dimensional way, the modifications produced on waves and wave-induced hydrodynamics by the presence of a fixed coastal defence structure. Consequently, the Navier–Stokes equations are numerically solved on a computational domain that represents a coastal area that is significantly larger than the structure. The flow motion equations are written in a moving curvilinear coordinate system that adapts to the positions of the free surface. At every time step of the simulation, the irregular and moving physical domain occupied by the water is transformed in a regular and fixed computational domain in which the upper boundary represents the free surface. Using this strategy, the propagation and evolution of the waves and the wave-induced hydrodynamics can be adequately simulated by using a small number of grid points over the vertical direction. Consequently, in [4], the computational costs are significantly reduced, and the modifications produced on the flow velocity fields by the presence of a fixed defence costal structure are carried out in a fully three-dimensional way.

Paper [3] of this Special Issue is another example of numerical study of the interaction between surface waves and fixed coastal defence structures. In [3], the effects on the sediment transport of the introduction of a submerged barrier designed to protect the entrance of a real harbour are numerically investigated. In this case, similarly to paper [4], the goal of the proposed numerical model is to simulate the modifications produced by the fixed structures on the wave and wave-induced flow velocity fields. In [3], differently from [4], the dimensions of the coastal area under investigation are too large to adopt a fully three-dimensional model. The numerical model proposed in [3] is a hybrid finite difference–finite volume shock-capturing scheme based on the numerical integration of depth-averaged flow motion equations written in a curvilinear coordinate system. The obtained flow velocity fields are used as input values of a solid transport numerical model, which is used to simulate the suspended sediment concentrations and update the bathymetry. This quasi-three-dimensional approach represents a good compromise between highly accurate representations and reasonable computational times and costs.

This Special Issue provides an example of different numerical approaches used to simulate wave–structure interaction problems of several types. It can be noted that the choice of the adopted numerical approach and related numerical model is governed primarily by the main goal of the numerical study and secondarily by the required accuracy of the numerical solution. In [5], the primary and secondary goals of the paper coincide, because the main objective of the authors is to propose a method to improve the accuracy in studying the characteristics of bottom sediments via the use of a seismic survey. As demonstrated in [5], a method based on factor decomposition of the wave signals in the spectral domain could significantly improves the quality of the marine surveys.

In the other papers of this Special Issue, a clear distinction between the primary and secondary goals of the proposed numerical studies can be used to better understand the reasons for different adopted numerical approaches. In the numerical studies [1,2], in which the main problem is the calculation of the dynamic response of a moving structure subjected to wave action, the most accurate numerical models are adopted for simulating the motion of the structure, while the calculation of the wave motion and hydrodynamics that produce the external loads, which represents the secondary goal, is carried out via the use of more simple and approximated approaches. On the other hand, in the numerical studies [3,4], in which the main goal is to evaluate the effect produced by fixed structures on the wave and hydrodynamic fields, the latter is simulated by using advanced numerical models. In fact, in [1,2] the main goal of the study is to evaluate the stresses exerted by water on a floating structure subjected to wave motion, such as wave energy converters or floating bridges. Consequently, in both the papers, a set of coupled models are proposed, in which the most accurate and time-demanding one is used to simulate the motion and dynamic response of the floating structure, which is discretized by a finite-element three-dimensional numerical model. In [3,4], the main goal of the study is to simulate the modifications produced on wave and hydrodynamic fields by the presence of fixed coastal structures. Consequently, for both papers, the proposal of advanced and accurate numerical models regarded those for the simulation of the propagation and evolution of the waves and wave-induced hydrodynamic fields in the coastal area in which the structure is placed. In this second type of numerical study, the choice of adopting a shock-capturing two-dimensional depth-averaged numerical model or a more complex three-dimensional one is mainly related to the dimensions of the studied coastal area and the duration of the simulated time interval. The goal of [4] is to simulate the modifications produced on local wave and hydrodynamic fields, during a storm, by the presence of a laboratory-scale prototype of a coastal defence structure. The reduced dimensions of the structure and coastal basin allow the authors to adopt a three-dimensional model without excessively increasing the computational costs. The main goal of [3] is to simulate the effects produced by a real-dimension submerged breakwater on wave fields, wave-induced currents, and solid transport processes in a coastal area whose horizontal dimensions are of the order of hundreds of meters. For this type of problem, the computational resources and time required by a three-dimensional model would be prohibitive, while the proposed numerical model, based on depth-averaged motion equations, provides acceptably accurate results in reasonable computational times.

Conflicts of Interest: The author declares no conflict of interest.

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