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Editorial

Wave Interactions with Coastal Structures

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Due to the ongoing rise in sea level and increase in extreme wave climates, consequences of the changing wave climate, coastal structures such as sea dikes and seawalls will be exposed to severe and frequent sea storms. Even though much research related to wave–structure interactions has been carried out, it remains one of the most important and challenging topics in the field of coastal engineering. The recent publications in the Special Issue "wave interactions with coastal structures" in the Journal *Marine Science and Engineering* contain a wide range of research, including theoretical/mathematical, experimental, and numerical works related to the interaction between sea waves and coastal structures. The research is related to conventional coastal hard structures in deep water zones and ones located in shallow water zones, such as wave overtopping over shallow foreshores with apartment buildings on dikes. The presented research findings increase knowledge of hydrodynamic processes, and new approaches and developments presented here will be a good benchmark for future works. The research papers published in the Special Issue are highlighted below with discussions of the approaches and developments.

Maiolo et al. [1] investigated wave propagation and transformation over a type of submerged breakwater. In particular, the intervention consists of protected nourishment, an environmentally friendly submerged structure aiming to protect the shoreline. The authors developed a simplified methodology employing a mathematical model to calculate the transmission of the incoming waves over such submerged structures. The study provides a reasonable estimation of the wave transmission, while the computational cost is significantly smaller than conventional numerical models. Such a methodology is helpful for engineering practices when many cases need to be simulated for different storms and sea-level rise scenarios, in combination with different coastal interventions. Furthermore, it can be used for further interventions such as nature-based solutions.

Altomare et al. [2] investigated the overtopping risk for pedestrians on sea dikes using experimental modelling carried out in a small-scale wave flume facility at Universitat Politecnica de Catalunya–BarcelonaTech, Spain. The structural setup comprised a 1:1 sloping smooth dike with foreshore slopes of 1:15 and 1:30, representing typical layouts of the urbanized coastal area north of Barcelona. Along this area, bike paths and railways run very close to the shoreline and have been exposed frequently to extreme storm conditions and overtopping events in the last decade. The flow depth and velocity characterize the stability of pedestrians; thus, these values were measured in the physical model. The overtopping flow velocity was measured by redundant systems composed of two high-speed cameras and two ultrasonic sensors. It is often a problem to measure the overtopping bore velocity on the dry dike since the conventional measurement system using an electric velocimeter does not work correctly at a location that changes wet and dry conditions by each overtopping event. The results indicate that average wave overtopping discharge and maximum individual overtopping volume are necessary but not sufficient variables to assess whether a scenario is safe or unsafe. Instead, the pedestrian hazard is proved to be linked to the combination of overtopping flow velocity and flow depth.

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Dan et al. [3] investigated the reduction of wave overtopping and force impact on storm walls on dikes and quays due to very oblique waves, where the wavefront forms an angle of $\geq 45^{\circ}$ with the structure. Such oblique waves need to be assessed when the quay and dike zones inside a harbour are located along the primary wave direction. The authors carried out the test in a wave basin equipped with a uni-directional wave generator (i.e., only long-crested waves were generated). The target structure is vertical storm walls on a dike with 1 in 2.5 slope and a vertical quay wall. Very oblique waves (angle between 45° and 80°) have been tested, measuring overtopping and force reduction with respect to perpendicular wave attacks. The study proposed coefficients of wave overtopping reduction and formulations of wave force reduction, both for very oblique wave cases. Physical models are still a major tool to investigate overtopping and force in engineering applications, not only due to the accuracy but also to the high demand of time and space (e.g., 1000 waves and 2D/3D domain), as can be seen in this work, while the application range of numerical models on wave–structure interaction is growing. Below, a review of six works are related to numerical modelling.

Suzuki et al. [4] investigated the overtopping risk on a dike in shallow foreshores using a non-hydrostatic wave model, SWASH; the topic is in line with Altomare et al. [2]. The model was first validated with a physical model to understand wave overtopping characteristics using different wave conditions and bathymetries. The results show that the overtopping risk is characterized by the time-dependent flow depth and velocity rather than maximum flow depth and velocity. If maximum values are used, the risk is overestimated. The work revealed that the structure configuration strongly influences the time-dependent values—even though the same average overtopping discharge, the risk is different by the flow depth and flow velocity combination. On top, it indicates a risk of return flows when a vertical structure leeward the dike. Such an investigation was achieved owing to the characteristics of SWASH: wave transformation and overtopping characteristics are reproduced accurately and are computationally less demanding.

Chang [5] applied a three-dimensional, fully non-linear potential wave model based on a curvilinear grid system to investigate the interaction of a solitary wave with vertical fully/partially submerged circular cylinders with/without a hollow zone. The model was validated with data in the literature and then was applied to study cases of wave-cylinder interaction. In general, 3D simulations are extremely demanding in terms of computational time and resources, and thus, it is not feasible for engineering practices. However, this paper tackled it by using a potential model. The target wave is one (i.e., solitary wave); thus, the computational time is shorter than a real case study, which often requires longer simulation (e.g., investigation of marine platforms). The work gives a good insight into the wave behaviour around a circular cylinder with or without hollow zones, while cases where the vortex effect is dominant cannot be dealt with due to the nature of potential models.

Li et al. [6] studied vertical breakwater stability under extreme waves. Vertical breakwaters are conventional coastal structures; thus, many investigations and knowledge on the stability of breakwaters have been accumulated in the literature. However, dealing with stability using numerical simulation is somewhat limited due to the complexity of the dynamic loading on the structure combined with overtopping waves. The authors investigated the pressure distribution under a condition with wave overtopping using a two-dimensional RANS model and discussed the potential risk of the failure mechanism.

Gruwez et al. [7] conducted an intensive validation of a two-dimensional RANS multiphase solver (i.e., OpenFOAM) for a case with sea dike in shallow foreshores. The authors compared the results of wave properties along the wave flume, wave runup and forcing in great detail with a quantified and objective validation. Based on it, the numerical model conducted in the study gives promising results in terms of wave propagation and force estimation without calibration after a convergence analysis. Evaluation/comparison of time series between the physical and numerical models is not a trivial task, but the authors proposed a useful classification of the relative refined index of agreement and corresponding rating.

Gruwez et al. [8] extended the work of Gruwez et al. [7] further, including the SWASH and DualSPHysics models, conducted through comparisons based on the same physical model validation case. It is an interesting work since each model is becoming very popular in coastal engineering and growing in the range of applications, yet the characteristics of the models are very different. The RANS model is a conventional numerical approach in coastal engineering, and the knowledge has been accumulated through a long history. A number of numerical schemes and techniques have been developed, and often, the model gives highly accurate modelling. DualSPHysics is a mesh-less model based on the smoothed particle hydrodynamics method (SPH). Compared to mesh-based approaches, SPH has a relatively short history (developed in the 70s of the last century for astrophysics and applied to fluid dynamics for the first time about 30 years ago). However, the method is becoming very popular due to its particle-based approach, capable of inherently catching non-linearities and very violent phenomena. SWASH is based on the non-linear shallow water equation with non-hydrostatic pressure; thus, it is suitable for the estimation of wave propagation in the shallow zone. Due to the nature of the equation, the computational time is much smaller than the RANS and SPH models. The three models are compared in terms of model accuracy and computational speed. The results indicate that all three models give a good accuracy for wave transformation and force estimation while OpenFOAM and DualSPHysics models give a slightly better representation in time series than the SWASH model. On the other hand, the SWASH simulation is much less time consuming compared to OpenFOAM and DualSPHysics. Each model has its characteristics with pros and cons; thus, the user needs to choose which type of numerical model is suitable. This work is one of the benchmark papers which contains a good discussion of detailed capabilities.

Hasanpour et al. [9] investigated tsunami-borne large debris flow and impact on coastal structures using a coupling model of SPH and FE (finite elements) in 2D. The developed model was validated with physical modelling in the literature. After validating the non-linear transformation of the tsunami wave, the debris–fluid interaction and the impact on a coastal structure, the model was further applied to debris–structure interaction. The result indicates the necessity of 3D simulation.

Altomare et al. [10] used the DualSPHysics model to understand the failure mechanism of the Pont del Petroli Pier in Spain, which occurred during the so-called "Storm Gloria" in January 2020. A preliminary 2D modelling was carried out to reproduce wave properties at the toe of the structure. Based on the water surface elevation and velocity field near the structure obtained in the 2D model, the 3D model case was carried out with the state-of-the-art inlet-wave-generation technique. The total number of particles of the 3D simulation was 1.7 million, with a physical time of 20 s, which corresponds to two to three waves characterizing the most extreme events, which were simulated (the run time was 9 hours). Such a simulation used to be very challenging due to the nature of the irregular wave and large domain, but this work proved that the DualSPHysics model can be applied to such events using a kind of nesting method (i.e., reproducing the incident wave time series from the 2D simulation). The simulation results have later been used to set up the experimental campaign carried out in a large-scale wave flume and will be exploited by local authorities to reconstruct the pier, a key element of the urban assets in the coastal town of Badalona. As this practice shows, numerical models can also assist the physical models instead of the physical model only feeding the validation data.

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