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Editorial

Interaction between Waves and Maritime Structures

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1. Introduction

Understanding the interaction between waves and maritime structures (IWMS) has been a primary concern for humans since ancient times, when they started sailing oceans and defending land from flooding and erosion.

However, understanding of this interaction started to truly develop only in the first half of twentieth century, when maritime engineering was recognized as a new discipline [1]. Since then, a remarkable body of research has been produced, both of a theoretical and, far more frequently, an experimental nature. Several water wave theories were developed in the nineteenth century (e.g., [2]) partly based on results from other branches of physics, such as thermodynamics [3], optics [4], and electromagnetism [5]. However, IWMS could not be described by theory alone. Starting from the early 1940s, the emerging "art and science of physical modeling" [6] had a tremendous impact on IWMS, putting a new design method at engineers' disposal. For example, it was thought that the stability of rubble mound breakwaters was a question of trial and error [7] for many years, until intensive laboratory testing (1942–1950) allowed Hudson [8], based on previous research by Iribarren [9], to propose a stability formula, which was widely employed in design practice until the early 1990s.

In recent years, the experimental approach to IWMS has taken further advantage of laboratory data by categorizing information into wide databases. This was the case, for example, for the 10,000 wave overtopping data collected within the framework of the European program CLASH (Crest Level Assessment of Coastal Structures by Full-scale Monitoring, Neural Network Prediction and Hazard Analysis on Permissible Wave Overtopping, [www.clash-eu.org]), which were then enlarged to 17,000 under conditions set out in EurOtop 2018 [www.overtopping-manual.com].

Clearly, large databases ease the analysis of relationships between predictive quantities and output variables and reduce the bias from laboratory/scale effects via a critical comparison of various datasets. Moreover, advanced numerical modeling techniques, such as computational fluid dynamics (CFD) or smooth particle hydrodynamics (SPH) have emerged as powerful experimental tools that may serve to either deepen laboratory findings or approach new or little-understood research topics [10–14].

2. Structure of the Special Issue

The arguments of the papers gathered within this Special Issue can be categorized into:

1. Structural performance, concerning the stability/integrity of the structure (or any part thereof);
2. Functional performance, i.e., related to the capability of the structure to meet the scope for which it has been designed.

In turn, Item 2 may be subdivided into:

- Hydraulic response, such as wave reflection, wave transmission, wave overtopping, etc.;

- Morphodynamic response, which is the shoreline and beach response to a structure placement;
- Floating body response, such as the oscillation of floating bodies or moored vessels.

This Special Issue includes 12 articles, four of which focus on structural performance and eight on functional response. The following section provides a brief summary of each of the contributions.

3. Article Overview

3.1. Contributions on Structural Processes

Two of the articles on structural performance deal with mound breakwaters; one addresses vertical seawalls and one analyzes the response of a complex offshore structure.

3.1.1. Rubble Mound Breakwaters: Effect of Permeability and Dynamics of Crown Walls

Eldrup et al. [15] deals with the role of notational permeability factor (NPF) in the hydraulic stability of rubble mound breakwaters. NPF is a leading variable of the widely employed van der Meer stability formulae [16] and has been introduced to globally account for the water seepage at a given cross-section material assemblage (including armor, underlayers, and core).

However, the original work by van der Meer indicated only four typical values of NPF, thereby creating some uncertainty in the engineering applications. Based on the analysis of new physical model tests conducted at Aalborg University (Denmark), the authors in [15] provide NPF values for seven different layer compositions and propose a pragmatic empirical method to help estimate the permeability parameter in non-tested situations.

The research of Macineira et al. [17] examines the dynamics of breakwater crown walls under wave actions. The proposed approach considers only two degrees of freedom, corresponding to the horizontal translation of the wall (normal to the breakwater axis) and the rotation in the cross-section plane. Stiffness is estimated as a function of the instantaneous wave force by assimilating the soil to an elastic medium, and damping effects are modeled as delayed soil reactions to the foundation movements. These assumptions result in simplified equations of motion, which can be iteratively integrated in the time domain. The article presents an application to the main breakwater of La Coruña, Punta Langosteira Port (Spain). A total of 752 simulations are carried out, in which both structure and soil characteristics are varied. Moreover, three loading types are considered, including permanent, sinusoidal, and impulsive chronograms.

3.1.2. Large Scale Experiments on Wave Loadings at Vertical Seawalls with Curved Outer Profiles

The study of wave loadings acting on the outer face of monolithic breakwaters and seawalls drew scientists' attention for many years, especially in the second half of the twentieth century. Stagonas et al. [18] concentrate on the effect of the wall curvature, which, despite having long been researched with respect to wave overtopping, is still a relatively unexplored facet of wave loading analysis. The authors discuss the results of regular wave large-scale physical model tests conducted on seawalls having an arch shape profile at their top. The angle in the center of the arch (α_e) varies between 48° and 90°; wave attacks are designed to induce both pulsating and impulsive pressures.

The research shows that the effect of α_e is negligible under quasi-static conditions while, in marked contrast, the mean of the maximum impulsive pressure and force peaks increases correspondingly by a factor of two. It is also shown that the deflection of the run-up wedge back to the incoming wave field has almost no effect on incident waves.

3.1.3. An Experimental Study on Dynamic Behavior of a Large Offshore Platform

Zhang et al. [19] performed physical model tests at the State Key Laboratory of Coastal and Offshore Engineering of Dalian University of Technology (China), with the purpose of investigating the dynamic response of a 10,000 ton offshore electrical platform.

First, the authors tackle the problem of scaling down the structural model, which is made of plexiglass; a hydroelastic similarity criterion is used, which guarantees both the hydraulic Froude condition and the similitude of elastic deformations.

The experiments are conducted in a basin, where irregular waves, currents, and wind (with three different angles of attack) are employed as climatic forcings. In addition, a set of regular wave tests are specifically conducted to gain a deeper insight into the platform hydrodynamic response.

Results highlight the role of wave slamming in amplifying both strains and accelerations and show that the maximum strain value under combined wave-current-wind conditions may be four times larger than that attained with waves alone.

3.2. Contributions on Functional Processes

Lo et al. [20] present a Navier–Stokes equations solver for two-phase flows, which uses the level set (LS) method [21] to track the interface between the two fluids and introduces a force density source term to account for the effects of immersed bodies. The force density term is then separately calculated via the immerse body (IB) concept [22]. The resulting Eulerian Cartesian/Lagrangian grid system does not require re-meshing procedures that involve coupled fluid-body interactions. The solver accuracy is checked against a number of cases, among which the most relevant to the scope of the present issue are those of wave propagation across a submerged barrier and the interaction of a floating body with a wave group. In these applications, the combined LS/IB approach is compared to the results of 2D laboratory experiments conducted by Beij and Battjes [23] and Hadzic et al. [24]. The comparisons appear encouraging.

3.2.1. Experimental Studies on Wave Overtopping

Ruol et al. [25] analyze the role of wave overtopping in the flooding of Piazza San Marco, Venice (Italy), which is one of the most stunning and architecturally valuable squares in the world. The authors reason that despite the Mo.S.E. (MOdulo Sperimentale Elettromeccanico) gates that protect the lagoon from flooding [www.mosevenezia.eu], Piazza San Marco could nonetheless be inundated, as waves generated by boats or SE winds may come over top of the Riva San Marco quay. Hence, to investigate this process, specific hydraulic model tests are carried out at the wave flume of the University of Padova (Italy). The experiments are necessary as the quay has a layout with a very mild slope that has been never been investigated before. Altogether, three different sections of the structure are considered under 10 random wave attacks and three water levels. Besides providing information on the risk of flooding at the specific area, the research adds to the database on wave overtopping with new accurate measurements that may aid both conceptual design and numerical modeling.

Formentin et al. [26] research the depth (h) and velocity (u) of the overtopping flow, which prove to affect a number of engineering phenomena, such as scour at the landward toe of breakwaters and wave overtopping propagation. In the article, impermeable trapezoidal dikes are considered, with a special focus on low-crested and submerged structures, which have been little researched thus far. Based on the analysis of 94 numerical flume random wave experiments and 60 2D hydraulic model tests, the dynamics of the overtopping flow along the dike crest are investigated in depth. Moreover, two new formulations for predicting h and u at the seaward edge of the structure crown are proposed. The new formulae keep the mathematical structure of the existing predictive tools [27], but modify the dependence on wave run-up and crest freeboard; moreover, new coefficients are introduced, which are functions of the dike offshore slope.

The article by Hernàndez-Fontes et al. [28] tackles the problem of the occurrence of “green water” events on a horizontal deck, which consist of a compact mass of water overtopping the structure, due, for example, to large wave–ship relative movements [29]. The authors carry out physical model experiments in a 1.95m long and 0.47m wide tank, where isolated bores are generated via a “wet dam–break” approach. This approach creates moving hydraulic jumps in the facility by removing a gate that separates two different water volumes. The experiments have a duration of nearly 3 s, and bore characteristics and green water flow are analyzed through a high-speed digital camera. The authors provide details on the air pocket trapped between the overtopping bore and the horizontal deck (air cavity), establishing an effective analogy with the kinematics of "flip-through" waves, which have been extensively investigated for vertical face breakwaters [30]. The time evolution of water elevation at the structure is also analyzed, and the backflow that follows the "green water" events is accurately studied.

3.2.2. Morphodynamic Response: Medium-Term Shoreline Analysis at a "Highly Structured" Coast

Buccino et al. [31] analyze the evolution of the Molise coast (South Italy) in the period 2004–2016. Using the linear regression rate concept [32] and numerical simulations, the authors assess the impact of a number of structural systems for shore erosion control, most of which include submerged/low-crested breakwaters [33,34] and groins [35]. The authors find out that most of erosion areas result from the existence of a net NW–SE littoral drift, which is blocked by the structures. Moreover, they show that, in spite of the inherent bimodality of the local wave climate, the shoreline evolution trend can be reasonably reproduced numerically via a single "equivalent" wave component from 10° N. However, it is argued that bimodality might have enhanced the erosion process, especially where structural measures alternate with undefended shoreline segments. This is because the reaches of coast between the structures would tend to experience erosion regardless of the wave direction.

3.2.3. Mechanical Response: Oscillation of a Ballasted Cylinder and Movements of Moored Vessels

Gabl et al. [36] notice that understanding the motion of water-filled bodies under wave excitation is of great interest to many fields of engineering, such as the design of wave energy converters (WECs) and ships transporting liquefied natural gas (LNG). However, they point out that most of the existing experimental studies consider only small motions, while the little research including the effect of large movements (mainly of a numerical nature) is conducted on specific (ship) geometries.

With the purpose of filling this gap, the article discusses the results of physical model tests carried out at the wave basin of the University of Edinburgh (UK). The experiments are conducted on a simple open-topped hollow cylinder, which is ballasted with either water or solid material to isolate and better comprehend the role of sloshing. Using constant amplitude sinusoidal waves with a frequency varying between 0.3 and 1.1 Hz, the authors find impacting waves with up to 20° pitch angles, whereas roll motion is generally small.

Nevertheless, under a specific frequency band, a sudden rotation switch from pitch to roll has been observed; this unexpected behavior has encouraged Gable et al. to conduct supplementary tests, the results of which are discussed in [37]. Here, variables that may affect the rotation switch are investigated, including position of the cylinder within the test tank, observation time, wave amplitude, wave direction, and mooring system.

The rationale of Sande et al. [38] might be well summarized by the maxim reported at the beginning of the article: "the better the vessels in port, the greater the economic returns". The authors argue that the "degree of comfort" of moored vessels depends to a large extent on the movements they experience during working operations. In addition, they claim that neither physical nor numerical models allow for the accurate reproduction of the effects on the cargo configuration of a continuous change in loading conditions.

Thus, a new method is developed, which relates moored vessels' degrees of freedom to ship dimensions and climatic forecast data. The approach uses simple transfer functions based on multivariate linear regression analysis and has been successfully validated against 27 vessels (15 bulk carrier and 12 general cargo) moored at the facilities of the outer port of Punta Langosteira, La Coruña (Spain).

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References

1. Goda, Y. Overview on the applications of random wave concept in coastal engineering. *Proc. Jpn. Acad. Ser. B Phys. Biol. Sci.* **2008**, *84*, 374–385. [CrossRef] [PubMed]
2. Stokes, G.G. On the theory of oscillatory waves. *Trans. Camb. Philos. Soc.* **1847**, *VIII*, 197–237.
3. Pelnard-Considère, R. Essai de Theorie de l'Evolution des Forms de Rivages en Plage de Sable et de Galets. *Journées de l'hydraulique* **1959**, *4*, 289–298.
4. Penney, W.G.; Price, A.T.; Price, A.T. The diffraction theory of sea waves and the shelter afforded by breakwaters. *Philos. Trans. R. Soc.* **1952**, *244*, 236–253. [CrossRef]
5. Mei, C.C.; Black, J.L. Scattering of surface waves by rectangular obstacles in waters of finite depth. *J. Fluid Mech.* **1969**, *38*, 374–385. [CrossRef]
6. Hughes, S.A. *Physical Models and Laboratory Techniques in Coastal Engineering*; World Scientific Publishing: Singapore, November 1993; p. 558.
7. D'Angremond, K.; van Roode, F.; Verhagen, H.J. *Breakwaters and Closure Dams*, 2nd ed.; VSSD: Delft, The Netherlands, 2008; p. 347.
8. Hudson, R.Y. Laboratory investigation of rubble-mound breakwaters. *J. Waterw. Harb. Div. Asce.* **1959**, *2171*, 611–635.
9. Iribarren, R. A formula for the calculation of rock fill dykes (Translation of "Una Fórmula Para El Cálculo De Los Diques De Escollera" Rev. De Obras Publica. 1938). *Bull. Beach Eros. Board* **1949**, *3*, 1–15.
10. Kamath, A. CFD Based Investigation of Wave-Structure Interaction and Hydrodynamics of an Oscillating Water Column Device. Ph.D. Thesis, Norwegian University of Science and Technology, Trondheim, Norway, December 2015.
11. Miquel, A.M.; Kamath, A.; Chella, M.A.; Archetti, R.; Bihs, H. Analysis of different methods for wave generation and absorption in a CFD-based numerical wave tank. *J. Mar. Sci. Eng.* **2018**, *6*, 73. [CrossRef]
12. Buccino, M.; Daliri, M.; Dentale, F.; Di Leo, A.; Calabrese, M. CFD experiments on a low crested sloping top caisson breakwater. Part 1. nature of loadings and global stability. *J. Ocean Eng.* **2019**, *182*, 259–282. [CrossRef]
13. Gotoh, H.; Khayyer, A. On the state-of-the-art of particle methods for coastal and ocean engineering, Coastal Engineering Journal. *Coast. Eng. J.* **2017**, *60*, 79–103. [CrossRef]
14. Meringolo, D.D.; Aristodemo, F.; Veltri, P. SPH numerical modeling of wave–perforated breakwater interaction. *Coast. Eng.* **2015**, *101*, 48–68. [CrossRef]
15. Eldrup, M.R.; Andersen, T.L.; Burcharth, H.F. Stability of Rubble Mound Breakwaters—A Study of the Notional Permeability Factor, Based on Physical Model Tests. *Water* **2019**, *11*, 934. [CrossRef]
16. Van der Meer, J.W. Conceptual Design of Rubble Mound Breakwaters. In Proceedings of the 23rd International Conference of Engineering, Venice, Italy, 4–9 October 1992.
17. Maciñeira, E.; Peña, E.; Sande, J.; Figuero, A. Dynamic Calculation of Breakwater Crown Walls under Wave Action: Influence of Soil Mechanics and Shape of the Loading State. *Water* **2019**, *11*, 1149. [CrossRef]
18. Stagonas, D.; Ravindar, R.; Sriram, V.; Schimmels, S. Experimental Evidence of the Influence of Recurves on Wave Loads at Vertical Seawalls. *Water* **2020**, *12*, 889. [CrossRef]
19. Zhang, D.-L.; Bi, C.-W.; Wu, G.-Y.; Zhao, S.-X.; Dong, G.-H. Laboratory Experimental Investigation on the Hydrodynamic Responses of an Extra-Large Electrical Platform in Wave and Storm Conditions. *Water* **2019**, *11*, 2042. [CrossRef]
20. Lo, D.-C.; Wang, K.-H.; Hsu, T.-W. Two-Dimensional Free-Surface Flow Modeling for Wave-Structure Interactions and Induced Motions of Floating Bodies. *Water* **2020**, *12*, 543. [CrossRef]
21. Osher, S.; Fedkiw, R.P. *Level Set Methods and Dynamic Implicit Surfaces*; Springer: Berlin, Germany, 2002.
22. Peskin, C.S. Flow patterns around heart valves: A numerical method. *J. Comput. Phys.* **1972**, *10*, 252–271. [CrossRef]
23. Beji, S.; Battjes, J.A. Experimental investigation of wave propagation over a bar. *Coast. Eng.* **1993**, *19*, 151–162. [CrossRef]
24. Hadzic, I.; Hennig, J.; Peric, M.; Xing-Kaeding, Y. Computation of flow induced motion of floating bodies. *Appl. Math. Model.* **2005**, *29*, 1196–1210. [CrossRef]

25. Ruol, P.; Favaretto, C.; Volpato, M.; Martinelli, L. Flooding of Piazza San Marco (Venice): Physical Model Tests to Evaluate the Overtopping Discharge. *Water* **2020**, *12*, 427. [CrossRef]
26. Formentin, S.M.; Gaeta, M.G.; Palma, G.; Zanuttigh, B.; Guerrero, M. Flow Depths and Velocities across a Smooth Dike Crest. *Water* **2019**, *11*, 2197. [CrossRef]
27. Van Gent, M.R. Wave overtopping events at dikes. In Proceedings of the 28th ICCE 2002, Wales, UK, 7–12 July 2002; Volume 2, pp. 2203–2215.
28. Hernández-Fontes, J.V.; Esperança, P.T.T.; Graniel, J.F.B.; Sphaier, S.H.; Silva, R. Green Water on A Fixed Structure Due to Incident Bores: Guidelines and Database for Model Validations Regarding Flow Evolution. *Water* **2019**, *11*, 2584. [CrossRef]
29. Greco, M. *A Two-Dimensional Study of Green-Water Loading*; Norwegian University of Science and Technology: Trondheim, Norway, 2001.
30. Hattori, M.; Arami, A. Impact breaking wave pressures on vertical walls. In Proceedings of the 23rd Conference on Coastal Engineering, Venice, Italy, 4–9 October 1992; ASCE: Reston, VA, USA, 1992; pp. 1785–1799.
31. Buccino, M.; Di Paola, G.; Ciccaglione, M.C.; Del Giudice, G.; Rosskopf, C.M. A Medium-Term Study of Molise Coast Evolution Based on the One-Line Equation and "Equivalent Wave" Concept. *Water* **2020**, *12*, 2831. [CrossRef]
32. Douglas, B.C.; Crowell, M. Long-term shoreline position prediction and error propagation. *J. Coast. Res.* **2000**, *16*, 145–152.
33. Van der Meer, J.W.; Briganti, R.; Zanuttigh, B.; Wang, B. Wave transmission and reflection at low-crested. structures: Design formulae, oblique wave attack and spectral change. *Coast. Eng.* **2005**, *52*, 915–929. [CrossRef]
34. Buccino, M.; del Vita, I.; Calabrese, M. Engineering modeling of wave transmission of reef balls. *J. Waterway Port. Coast. Ocean Eng.* **2014**, *140*, 04014010. [CrossRef]
35. Kraus, N.C.; Rankin, K.L. *Functioning and Design of Coastal Groins: The Interaction of Groins and the Beach Processes and Planning*; Coastal Education and Research Foundation: West Palm Beach, FL, USA, 2004.
36. Gabl, R.; Davey, T.; Nixon, E.; Steynor, J.; Ingram, D.M. Comparison of a Floating Cylinder with Solid and Water Ballast. *Water* **2019**, *11*, 2487. [CrossRef]
37. Gabl, R.; Davey, T.; Ingram, D.M. Roll Motion of a Water Filled Floating Cylinder—Additional Experimental Verification. *Water* **2020**, *12*, 2219. [CrossRef]
38. Sande, J.; Figuero, A.; Tarrío-Saavedra, J.; Peña, E.; Alvarellos, A.; Rabuñal, J.R. Application of an Analytic Methodology to Estimate the Movements of Moored Vessels Based on Forecast Data. *Water* **2019**, *11*, 1841. [CrossRef]