Advanced Research for Coastal Infrastructure Resilience, Data-Driven Management, and Sustainable Water Solutions

Coastal and ocean engineering is undergoing a profound transformation. Driven by increasingly frequent extreme events, rising anthropogenic pressures, accelerating climate change, and the transition toward sustainable economies, the discipline is redefining how coastal environments and marine infrastructure are designed, managed, and protected.

This Special Issue of *Coastal and Ocean Science and Engineering* brings together five scientific contributions that address, from different yet complementary perspectives, some of the most pressing challenges faced by contemporary coastal and maritime communities. Collectively, these papers underscore the importance of a multidisciplinary approach grounded in robust physical experimentation, advanced numerical modelling, accessible monitoring technologies, and sustainable environmental solutions.

The articles span a broad thematic spectrum—from wave–structure interaction to coastal monitoring based on open-access datasets; from breakwater damage evolution to advanced modelling frameworks for port navigation safety; and from infrastructure resilience to innovative treatments for environmentally harmful wastewater. Together, they provide a comprehensive snapshot of current scientific progress and offer practical tools for researchers, engineers, planners, and decision-makers.

1. Experimental advances in wave loading on crown walls

Eldrup et al. present an extensive physical modelling study—comprising more than 590 flume tests—investigating the influence of structural permeability and wave steepness on wave-induced loads acting on crown walls. By benchmarking the widely used formulations proposed by Nørgaard et al. and Molines et al., the authors deliver unprecedented insights into their accuracy, applicability, and limitations.

The results substantially expand the experimental database for non-breaking wave conditions, identify areas where existing predictive models require refinement, and provide valuable guidance for future design standards. This contribution represents a significant advancement in the understanding of wave–structure interactions in rubble-mound breakwaters.

2. Data-driven coastal management using open-access datasets

Rumenović et al. introduce a replicable and cost-effective framework for coastal monitoring and countermeasure planning based entirely on publicly available datasets. Developed within the ClimBeach project, the methodology integrates meteorological, oceanographic, and remote-sensing data to assess shoreline evolution, classify beach types, and support the selection of appropriate intervention strategies.

This work is particularly relevant for regions lacking continuous in-situ monitoring infrastructure, offering a scalable and practical pathway toward informed coastal management under increasing climate-driven pressures.

3. Breakwater damage evolution: integrating 2D and 3D insights

Lemos et al. revisit the classical Melby and Kobayashi formulation for damage evolution in rubble-mound breakwaters, extending its applicability to armour layers composed of tetrapods and explicitly incorporating three-dimensional bathymetric effects through large-scale physical model experiments.

The study proposes improved empirical coefficients and demonstrates how interactions between wave fields and three-dimensional structural geometry govern long-term damage progression. The results provide enhanced predictive capabilities for structural resilience assessment and maintenance planning.

4. Integrated modelling for ship accessibility and port safety

Pinheiro et al. propose a comprehensive numerical framework that couples multi-scale wave propagation models with three-dimensional hydrodynamic simulations to evaluate ship motions and under-keel clearance in exposed ports.

The methodology supports both planning-level assessments and real-time operational decision-making and forms the foundation of the SAFEPORT Early Warning System. Its operational application demonstrates how high-resolution modelling can significantly enhance navigational safety, reduce operational disruptions, and strengthen port resilience under challenging sea conditions.

5. Sustainable electrochemical treatment of membrane-cleaning wastewater

Licht et al. investigate electrocoagulation as a sustainable treatment solution for wastewater rich in free chlorine generated during membrane-cleaning procedures in drinking water and desalination plants. Their experimental results demonstrate high removal efficiencies and highlight the conversion of free chlorine into chloride as a key environmental benefit.

This study aligns with global efforts to reduce chemical loads and environmental impacts in water treatment facilities, offering a practical pathway toward greener and more sustainable operational practices.

Collective Themes and Emerging Directions

The contributions gathered in this Special Issue reflect a rapidly evolving discipline, increasingly shaped by the integration of scientific rigor, technological innovation, and sustainability-driven approaches. Across the papers, three overarching themes emerge.

First, experimental and numerical rigor remains fundamental for understanding, modelling, and predicting complex coastal processes—from wave loading mechanisms to interactions between three-dimensional geometries and dynamic wave fields. Second, the rise of data-driven methodologies is democratizing access to coastal monitoring, enabling informed decision-making even in regions lacking dedicated observational infrastructure. Third, the development of sustainable technological solutions is reducing environmental impacts while supporting the transition toward more responsible and resilient operational practices.

Although diverse in scope, these research directions converge toward a shared objective: enhancing the resilience of coastal and maritime systems through innovative, multidisciplinary, and future-oriented approaches.

Concluding Remarks

Taken together, the studies presented in this Special Issue reaffirm the central role of coastal and ocean engineering in protecting, managing, and enhancing coastal environments and marine infrastructure. The integration of high-quality experimentation, robust modelling, open-access data, and sustainable technologies has become a cornerstone for addressing increasingly complex societal and environmental challenges.

This Special Issue is intended not only as an up-to-date scientific reference but also as an invitation to continued interdisciplinary collaboration and innovation, with the ambition of contributing to safer, more adaptive, and more sustainable coastal futures.

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