Frontiers in Coastal Hydrodynamics, Advanced Numerical Modelling, and Multi-Scale Experimental Analysis

Volume I-2025 of Coastal and Ocean Science and Engineering (COSE*)* brings together five cutting-edge contributions that collectively reflect the evolution of coastal and ocean engineering towards increasingly integrated, data-driven, and physics-informed approaches.

The five contributions included in this Volume were originally presented at the 11th edition of the Short Course/Conference on Applied Coastal Research (SCACR), held in Dubrovnik, Croatia, from 24 to 26 September 2025. SCACR events are designed to promote the exchange of state-of-the-art advances in coastal and port engineering by combining scientific knowledge, methodological innovation, and practical application. Bringing together MSc and PhD students, experimental and field researchers, theorists, and numerical modellers, SCACR has become a vibrant hub for the global coastal and marine engineering community.

This Special Issue captures a significant moment for the discipline: advanced computational models are converging with high-fidelity hydraulic experiments, enabling researchers to explore coastal processes with a level of detail, accuracy, and scalability that would have been unthinkable only a decade ago.

The articles gathered here illustrate how the field is moving beyond traditional paradigms—such as purely empirical design rules or isolated laboratory testing—towards unified frameworks that combine nonlinear wave dynamics, multidirectional wave decomposition, fully three-dimensional sediment morphodynamics, phase-resolving diffraction modelling, and rigid-body simulations of large armour units. Together, these studies represent a decisive step towards predictive coastal engineering supported by multiphysics models and validated through rigorous experimentation.

What emerges is a clear vision of the future of coastal science: a discipline in which hydraulic laboratories, numerical wave basins, and high-performance computing environments operate in synergy, continuously exchanging data, validation, and conceptual advances.

This editorial provides an overview of the scientific contributions of each paper and highlights the broader transformations they collectively signal for the field.

1. Advances in Hydraulic Model Testing: Towards High-Resolution Physical Insight

The opening contribution by Andersen, Eldrup, and Iversen revisits the foundations of hydraulic physical modelling with renewed emphasis on precision, reproducibility, and experimental fidelity. The paper synthesises recent developments in wave generation, absorption techniques, instrumentation, calibration procedures, and uncertainty quantification.

The authors describe state-of-the-art approaches for generating highly controlled multidirectional wave fields and highlight advances in active and passive absorption systems, modern wave-gauge configurations, non-intrusive measurement techniques, and the integration of physical models with real-time numerical support tools. Their work underscores a central message: physical modelling is not being replaced by numerical modelling—rather, it is being strengthened, refined, and integrated with it. This hybrid perspective establishes the conceptual foundation for the subsequent contributions in this Volume.

2. Multidirectional Nonlinear Wave Decomposition: From Theory to Experimental Validation

Iversen et al. present one of the most technically sophisticated contributions of the Volume: the first experimental validation of the NL-SORS (Nonlinear Single-Summation Oblique Reflection Separation) method, a significant advancement in wave-field analysis for short-crested, nonlinear sea states.

Although methods for separating incident and reflected wave fields have long existed for long-crested or linear conditions, the decomposition of nonlinear multidirectional waves has remained a persistent challenge. The NL-SORS method addresses this gap through a robust frequency-domain least-squares framework capable of estimating incident, reflected, bound, and free wave components with high stability.

This contribution is particularly notable for:

- Demonstrating the method using physical rather than synthetic data;
- Establishing robustness across varying degrees of directional spreading and nonlinearity;
- Enabling reconstruction of full three-dimensional directional spectra and wave trains.

The study represents a major step forward for physical modelling facilities, which increasingly require accurate wave-field decomposition in order to relate structural response to truly incident wave conditions.

3. High-Fidelity Modelling of Local Scour Around Circular Structures

Ebrahimi, Wang and Bihs present a detailed and rigorous investigation of local scour using the open-source REEF3D CFD framework. The study stands out for its implementation of:

- Fully three-dimensional RANS modelling;
- Dynamic free-surface capture using the level-set method;
- A sediment transport module coupled with morphological evolution;
- A direct-forcing immersed boundary method for enhanced numerical stability.

The authors address one of the most fundamental—and notoriously complex—problems in coastal engineering: predicting the formation and temporal evolution of scour holes around piles and piers. By validating the model against experimental data, including scour depth and spatial patterns, the study demonstrates that the enhanced REEF3D implementation reproduces scour geometry with remarkable accuracy.

Beyond its immediate application, the work highlights a broader trend: high-resolution sediment morphodynamics is becoming computationally feasible and increasingly integral to design-level studies.

4. Diffraction Modelling with a Three-Dimensional Non-Hydrostatic Solver: Bridging Analytical Theory and Real-World Harbours

Becker, Wang and Bihs provide a comprehensive assessment of wave diffraction around breakwaters using the non-hydrostatic model REEF3D::NHFLOW. The study employs a two-level validation strategy:

1. Analytical benchmarking against the classical Sommerfeld solution, achieving excellent agreement and a very low RMSE (0.012);
2. Application to a real harbour (Sirevåg, Norway), where NHFLOW reveals significantly different wave penetration patterns compared with the spectral model SWAN.

The results demonstrate that phase-resolving models provide fundamentally different—and in many cases more physically realistic—insights into wave propagation within harbour basins, particularly with regard to energy penetration near openings and the role of diffraction in shaping nearshore wave climates.

The study makes a compelling case for incorporating non-hydrostatic solvers into the design workflow for port engineering and coastal infrastructure exposed to complex wave fields.

5. Coupled CFD–DEM Modelling of Large Armour-Unit Interactions

The final contribution by Larkermani et al. extends numerical modelling into a domain of central importance for breakwater engineering: the simulation of motion, interaction, collision, and stability of individual large armour units.

The authors introduce a high-fidelity CFD–DEM framework integrating:

- A Navier–Stokes solver with high-order WENO discretisation;
- A Direct Forcing Immersed Boundary Method for realistic fluid–solid interaction;
- A multi-level collision detection algorithm;
- Six-degrees-of-freedom rigid-body motion;
- A viscoelastic contact model.

This fully resolved CFD–DEM approach enables the capture of rocking, displacement, interlocking, collision dynamics, and complex rearrangements of armour units under hydrodynamic loading.

The implications are profound: this methodology opens the door to a new generation of breakwater design based not solely on empirical coefficients, but on physically resolved simulations approaching prototype scale.

Collective Themes and Emerging Directions

Across these five contributions, several unifying themes emerge:

1. *The fusion of experimental and numerical hydrodynamics*

Physical model tests are increasingly complemented by real-time numerical support, advanced wave decomposition techniques, and data-assimilation frameworks.

2. *The rise of open-source, high-fidelity modelling ecosystems*

The REEF3D suite features prominently in four of the five papers, underscoring the growing importance of transparent, reproducible, and community-driven modelling platforms.

3. *A growing focus on nonlinear, multidirectional, and multiphase processes*

Coastal systems are inherently complex—and the tools used to study them now reflect that complexity more faithfully than ever before.

4. *Engineering applications grounded in physics-based understanding*

From scour evolution to harbour wave penetration and armour-unit dynamics, each contribution strengthens design-level capabilities through mechanistic insight.

5. *A shared trajectory towards predictive coastal engineering*

The advances presented here collectively move the discipline towards models that are not merely descriptive, but predictive—capable of anticipating structural performance, morphological evolution, and coastal risk under future conditions.

Concluding Remarks

Volume I-2025 of COSE, a special issue, offers a compelling snapshot of the intellectual energy currently driving coastal and ocean engineering. It showcases a community committed to methodological rigour, innovation, and openness—and to developing tools and insights that directly support coastal resilience in an era of accelerating environmental change.

It is also noteworthy that all five papers included in this Volume were first presented at SCACR 2025 in Dubrovnik. Their inclusion reflects not only the scientific quality of the event but also its role as an incubator of emerging ideas, interdisciplinary collaboration, and the next generation of coastal engineers. The scientific dialogue fostered at SCACR aligns strongly with the themes highlighted in this Special Issue, reinforcing the importance of community-driven knowledge exchange.

These contributions will undoubtedly serve as reference points for ongoing advances in hydrodynamics, sediment processes, numerical modelling, and coastal infrastructure design.

We hope that readers will find in this Volume both inspiration and practical guidance, and that the work presented here will continue to stimulate scientific dialogue and interdisciplinary collaboration.

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