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Editorial

Advances in Marine Engineering: Geological Environment and Hazards—3rd Edition

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1. Introduction

Following the success of the first two Special Issues [1–4] on "*Advances in Marine Engineering: Geological Environment and Hazards*," this third installment continues to present cutting-edge research in the field. This Special Issue (SI) was organized by Prof. Dr. Xingsen Guo from Ocean University of China, University College London, and the University of Cambridge; Prof. Dr. Xiaolei Liu from Ocean University of China; Prof. Dr. Tingkai Nian from Dalian University of Technology; and Prof. Dr. Thorsten Stoesser from University College London. The primary aim of this SI is to gather together high-quality papers highlighting the latest advancements in marine geological environments and hazards, marine engineering geology, marine hydrodynamics, marine fluid mechanics, and marine geotechnical engineering.

As marine engineering continues to advance toward deeper waters and more challenging environments, the complexity of geohazards and the uncertainty of seafloor conditions pose increasing risks to offshore infrastructure. The contributions in this Special Issue collectively address these critical challenges by spanning the full spectrum from seabed characterization and environmental process mechanics to engineering response and risk mitigation. Through multi-source geophysical data integration, controlled physical experiments, cutting-edge numerical simulations, and data-driven prediction frameworks, the included studies provide new insights into submarine gravity flows and fluid migration risks, hydrodynamic transformation under climate-driven sea level rise, contaminant mobilization under storm-induced seabed liquefaction, and the deformation and stability of marine soils and foundations under cyclic or impact loading. In parallel, advanced computational and machine learning approaches enhance predictive capability for novel ocean engineering systems—from deep sea mining vehicles to bio-inspired hydrodynamic structures.

Altogether, this Special Issue comprises 1 review paper [5] and 11 research papers [6–16], contributed by 63 scholars from leading universities, research institutions, and industry worldwide. Collectively, these contributions present state-of-the-art concepts, innovative methodologies, and high-quality data that advance both the knowledge and practice of marine geological environments and hazards. The following sections provide

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a concise synthesis of the main findings and significant contributions of each paper included in this SI.

2. Papers Details

Zhang et al. [5] presented a comprehensive review of the interactions between submarine gravity flows and seafloor pipelines, synthesizing recent advances in understanding how flow characteristics, pipe geometry, seabed conditions, and environmental factors jointly influence hydrodynamic loading and pipeline response. The authors highlight key controlling parameters—including Reynolds number, pipeline span ratio, impact angle, surface roughness, and temperature—and discuss the additional complexity introduced by multi-pipe configurations and flow-induced vibration. They identify major limitations in existing research, such as the scarcity of physical experiments, oversimplified seabed boundary conditions, and uncertainties associated with non-Newtonian rheological models commonly used for debris flows. Zhang et al. further outline practical mitigation strategies and emphasize future research priorities, particularly the development of fully coupled 3D multi-physics models and improved assessments of fatigue and stability under extreme gravity flow events. This review provides valuable guidance for the risk assessment and design optimization of offshore pipeline systems subject to submarine gravity flow hazards.

Tao et al. [6] employed a multi-source data fusion strategy integrating 3D seismic data, shipborne multibeam bathymetry, and high-resolution AUV surveys to construct a refined seabed terrain inversion model for the Qiongdongnan Basin. Their analysis successfully identified complex geomorphologic features—including escarpments, fissures, faults, and multi-phase mass transport deposits—and revealed marked improvements in inversion accuracy over single-data approaches. By combining seismic attribute extraction with geostatistical evaluation, the authors further established a vertical risk zonation framework for shallow gas, demonstrating that the most significant enrichment occurs at depths between 200 and 300 m under the joint influence of fault-guided migration and sedimentary compaction structures. These results provide valuable technical support for deep water engineering design, hazard mitigation, and safe offshore energy development in the South China Sea.

Yu et al. [7] developed a two-dimensional MIKE 21 hydrodynamic model to evaluate how projected sea level rise alters tidal wave propagation throughout the Yangtze River Estuary under varying river discharge conditions. Their simulations demonstrate that sea level rise consistently elevates average water levels while modifying tidal amplitudes in a spatially heterogeneous manner, with the most pronounced changes occurring near Xuliujing, where tidal dynamics transition between estuarine and riverine regimes. The study reveals that rising sea levels enhance tidal current velocities in most estuarine sections and reduce tidal wave attenuation along upstream reaches, causing the tidal limit to shift further inland. These findings highlight the increasing sensitivity of the estuary's hydrodynamics to future sea level scenarios and provide important guidance for flood risk assessment, navigation safety, and estuarine management in the Yangtze River basin.

Lu et al. [8] performed controlled wave flume experiments to quantify how wave-induced resuspension and sediment liquefaction mobilize petroleum-derived PAHs from silty seabeds in the Yellow River subaqueous delta. Their results show that increasing wave intensity—from static conditions to 5 cm and then 12 cm waves—substantially enhances suspended sediment concentration and triggers excess porewater pressure leading to sediment liquefaction. This liquefaction state dramatically increases PAH release, with dissolved PAH concentrations rising up to fivefold compared with static diffusion, and facilitates deeper vertical migration of low-molecular-weight PAHs within the sediment column. The study highlights the critical role of hydrodynamic disturbances in controlling PAH mobility and underscores the elevated pollution risks during storm events, providing essential insights for environmental assessment and coastal management in deltaic environments.

Liu et al. [9] investigated the mechanical behavior of marine soft soil under cyclic loading by integrating dynamic triaxial testing with discrete element simulations to capture both macroscopic deformation and micromechanical evolution. Their results show that increasing water content, confining pressure, and dynamic stress ratios significantly amplify strain accumulation, hysteresis loop expansion, and energy dissipation, while high moisture levels (e.g., 60%) trigger pronounced shear band development and structural degradation. The DEM analysis elucidates particle rearrangement, lubrication effects, and porosity evolution, offering mechanistic insights consistent with laboratory observations. The combined macro–micro framework provides a more comprehensive understanding of soil softening and instability under repeated loading, delivering valuable guidance for the design, assessment, and reinforcement of marine soft soil foundations for coastal urban infrastructure.

Ge et al. [10] proposed an explainable ensemble learning framework for predicting the compression index of clays, a critical parameter in geotechnical design for clay-rich coastal environments. Using a global dataset of 1080 samples, the authors evaluated multiple ensemble models—including random forest, gradient boosting decision trees, extreme gradient boosting, and a stacking ensemble—and demonstrated that the stacking model achieved the highest predictive accuracy. To handle missing data, they employed a K-nearest neighbors imputation approach, which effectively preserved the underlying data distribution and enhanced model robustness across varied soil conditions. Furthermore, SHAP-based interpretability analysis identified the initial void ratio and natural water content as the most influential factors governing compression index predictions. This work highlights the strong capability of ensemble learning in modeling clay compressibility and provides useful insights for geotechnical and coastal infrastructure design, particularly in regions with heterogeneous soil properties and incomplete datasets.

Wei et al. [11] conducted centrifuge model tests to investigate the uplift behavior of single-cylinder suction caisson foundations in high-sensitivity marine clay, focusing on performance degradation under vertical cyclic loading. By preparing sensitive soil through a freeze–thaw procedure, they demonstrated that cyclic uplift capacity decreases rapidly with increasing soil sensitivity and load cycles, accompanied by accelerated cumulative displacement until stabilization. The results further reveal that the secant stiffness of the load–displacement hysteresis loops follows a logarithmic relationship with both cyclic loading number and soil sensitivity. This study provides valuable insights into the uplift capacity and stiffness evolution of suction caisson foundations in soft, highly sensitive seabeds, offering practical guidance for the design and long-term safety of offshore wind energy infrastructure in clay-rich regions.

Liu et al. [12] performed wave flume experiments supported by image analysis to examine the formation and evolution of interfacial waves within liquefied submarine sediments and their role in driving sliding zone development. Their results show that interfacial waves emerging after seabed liquefaction govern the progressive downslope movement of sediment and dynamically control both the position and thickness of the sliding zone, which corresponds closely to the liquefaction depth. The interfacial wave height increases with greater liquefaction depth—reaching up to 17.5% of the surface wave height—and yields a maximum sliding zone width ratio of 0.25. These waves effectively transfer surface-wave energy into deeper soil layers, extending the lower boundary of the sliding zone. The study provides important theoretical insights for predicting and mitigating seabed sliding during extreme storm events.

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Dai et al. [13] employed high-fidelity large-eddy simulations to investigate the flow field around a cuboid artificial reef under different inflow angles, aiming to reveal how reef orientation affects hydrodynamics and turbulence characteristics. Their simulations, validated against flume experiments, demonstrate that an inflow angle of 45° produces the most favorable flow environment, yielding the longest recirculation bubble, enhanced upwelling, and the largest wake volume compared with 0° and 90° configurations. The study also identifies intensified shear-layer interactions and the generation of torn horseshoe vortices and hairpin vortices as key mechanisms promoting turbulent mixing. These findings provide important guidance for optimizing artificial reef design and deployment strategies to improve ecological performance and marine habitat enhancement.

Gong et al. [14] used high-resolution large-eddy simulations to analyze flow dynamics and momentum exchange mechanisms in an isolated semi-circular lateral cavity influenced by longshore currents. Their numerical model, validated against flume measurements, revealed that increasing the Reynolds number intensifies shear-layer instabilities, promotes upstream migration of the primary vortex core, and enhances secondary vortex development inside the cavity. The study further showed that Kelvin–Helmholtz vortices dominate periodic mass and momentum exchange across the cavity mouth, transitioning from viscosity-damped turbulence at lower Reynolds numbers to fully developed shedding downstream. These findings advance the understanding of cavity-induced hydrodynamics and provide useful implications for optimizing nature-based coastal engineering strategies and sediment retention designs in curved shoreline systems.

Qu et al. [15] performed a comparative seismic and well-based analysis of deep water sedimentary architectures on the central West African passive margin, contrasting the Lower Congo Basin and the Niger Delta by integrating 4039 km of seismic lines, RMS amplitude slices, well logs from 18 key wells, and volumetric sediment budget metrics. Their work demonstrates a striking dichotomy: since the Eocene, the Lower Congo Basin developed a retrogradational, narrow-shelf system dominated by erosive channel–levee complexes and terminal lobes, whereas the Niger Delta evolved a progradational, broad-shelf system characterized by fan lobes and delta-fed turbidites. Quantitative analysis identifies diapir-induced seafloor relief and basement uplift as first-order controls that redirect sediment pathways and amplify facies heterogeneity, while the shelf-break configuration and oceanic relief play subordinate roles. By explicitly linking salt/mud tectonics, shelf slope geometry, and sediment supply, the study refines source-to-sink models and offers practical guidance for predicting reservoir distribution and reducing exploration risk in diapir-affected passive margins.

Zeng et al. [16] introduced a hybrid computational framework that combines the Coupled Eulerian–Lagrangian (CEL) finite element method with a random forest (RF) machine learning algorithm to predict the landing penetration of a full-scale deep sea mining vehicle (DSMV) on ultrasoft seabed sediments. Their high-fidelity CEL simulations incorporated strain-softening and rate-dependent soil behavior, showing that penetration depth increases with soil sensitivity, descent velocity, and vehicle weight, but decreases with higher undrained shear strength and larger track contact area. To address the substantial computational cost of FEM analyses, the authors trained an RF model using the simulation dataset, achieving strong predictive performance ($R^2 > 0.94$) for normalized penetration depth. This integrated FEM–ML approach offers an efficient and reliable tool for optimizing track geometry and landing strategies, ultimately improving the operational safety and stability of DSMVs in deep sea mining applications.

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Short Biography of Authors

Xingsen Guo is a Professor and Doctoral Supervisor at the Ocean University of China, a Marie Skłodowska-Curie Fellow at the University of Cambridge, and a Research Fellow at the University College London. His research primarily focuses on marine engineering geology and related environmental challenges. He earned his PhD from the Dalian University of Technology (DUT) in 2021. Prof. Guo has published over 90 peer-reviewed articles in leading journals such as Coastal Engineering and Engineering Geology, including multiple ESI hot and highly cited papers. He serves on the editorial boards of several journals, including Marine Georesources & Geotechnology. His accolades include the International Consortium on Geo-disaster Reduction (ICGdR) Outstanding Young Scientist Award, the BGA Poster Award, the JMSE Travel Award, and multiple Excellent Doctoral Dissertation Awards from ICGdR, the Chinese Society for Rock Mechanics & Engineering, Liaoning Province, and DUT. He has also been recognized among the World's Top 2% Scientists.

Xiaolei Liu is a Professor and Doctoral Supervisor at the Ocean University of China (OUC). He serves as the Director of the Shandong Provincial Key Laboratory of Marine Engineering Geology and the Environment and the Chairman of the Committee on Marine Geo-disaster and Geo-environment (TC-4) within the International Consortium on Geo-disaster Reduction (ICGdR). His research focuses on marine engineering geology and geohazards, specifically addressing the phase transition mechanisms of submarine sediments, the evolution of fluidized sediment movements, and advanced probing techniques for the seabed interface layer. Prof. Liu's work as a Principal Investigator is distinguished by a strong record of innovation and scholarship, including leadership of over 20 national and industry-sponsored projects, more than 130 publications in leading international journals, over 70 invention patents, and several prestigious awards.

Tingkai Nian is a Professor and the leader of the Marine Geohazard Research Group in the State Key Laboratory of Coastal and Offshore Engineering at Dalian University of Technology and a Senior Research Scholar at University College London. Prof. Nian's research interest is in developing advanced numerical, experimental and AI tools and their application to solve marine soil mechanics and geohazards problems. He has led more than 10 national-level research projects and co-authored over 150 peer-reviewed journal papers (SCI/EI-indexed). Prof. Nian has held over 40 invention patents and software copyrights, and obtained the Technology Invention Award from the International Consortium on Geo-disaster Reduction (ICGdR), First Prize for Scientific and Technological Progress in Liaoning Province, and appointment as a Leading Talent in Science and Technology Innovation. He also serves as Associate Editor-in-Chief of the journal of Geoenvironmental Disasters, Deputy Director of the Coastal and Offshore Engineering Disaster Environmental Protection Special Committee of the Chinese Seismological Society.

Thorsten Stoesser is the Leader of the Fluid Mechanics Research Group in the Department of Civil, Environmental and Geomatic Engineering at the University College London. His research interest is in developing advanced Computational Fluid Dynamics (CFD) tools and their application to solve environmental fluid mechanics problems. Thorsten has published over 100 peer-reviewed journal papers on developing, testing and applying advanced CFD methods to predict the hydrodynamics and transport processes in rivers, estuaries and coastal waters, fluid-structure interaction of marine turbines, and the nearfield dynamics of jets and plumes. For his research Prof. Stoesser received twice the American Society of Civil Engineers (ASCE) Karl Emil Hilgard Hydraulic Prize (2012 and 2016), in 2015 he won the International Association of Hydro-environmental Research (IAHR) Harold Shoemaker Award and in 2016 he won the Institution of Civil Engineers' George Stephenson medal. He has received over £5M in funding from industry, government institutions and research councils including the DFG (Germany), NSF (USA) and EPSRC (UK).