Structure–Seabed Interactions in Marine Environments

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The phenomenon of soil–structure interactions in marine environments has attracted much attention from coastal and geotechnical engineers and researchers in recent years. One of the reasons for the growing interest is the rapid development of marine resources (such as the oil and gas industry, marine renewable energy, and fish farming industry), as well as the damage to marine infrastructure that has occurred in the last two decades. To assist practical engineers in the design and planning of coastal geotechnical projects, a better understanding of the mechanisms of structure–soil interactions in marine environments is desired. The purpose of this Special Issue is to report the recent advances in the problems of structure–seabed interactions. This Special Issue will provide practical engineers and researchers with information on recent developments in this field.

Nine (9) papers are included in this Special Issue: one review article [1] and eight research articles covering two main themes—(1) the mechanisms of marine sediments in the Yellow River Delta [2] and a field study [3] and (2) structure–seabed interactions in the vicinity of tunnels [4,5], spudcans [6], pile foundations [7], breakwaters [8], and pipelines [9]. More details on each contribution are summarized here.

In the early stages of research on this topic, most theoretical studies were based on linear wave theory and analytical approximations for wave-induced seabed responses without a structure or in front of a structure. This is not particularly relevant to the interactions between seabeds and structures due to the difficulty of handling the complicated boundaries near the structure. Therefore, numerical simulation, as well as physical modeling, are effective techniques.

Diaz-Carrasco et al. [1] summarize the recent advances in numerical simulations for wave–structure–seabed interactions with a focus on breakwaters. In this review article, the authors discuss the concept of scour and how the wave–structure–seabed interaction process contributes to the scour for the design of marine protection structures. They outline the most recent studies in the field, many of which are based on one-way coupling. In addition to the conventional approach to wave–structure–seabed interactions, the authors outlined the full multi-phase approach, which includes air, water, and sediment phases in both mass and momentum conservation equations. However, this review article focuses on the oscillatory mechanism only and limits its scope to poro-elastic seabed models. Other mechanisms, such as residual liquefaction and associated poro-elastoplastic models (which are equally important in the field of wave–seabed–structure interactions), are not included.

Marine sediments have quite different soil properties and mechanical behaviors compared with the onshore soils due to various physical processes and loading mechanisms in marine environments. It is particularly important to gain a better understanding of the physical properties of marine sediments and the associated changes under dynamic loading for the design of foundations of marine infrastructures.

The highly concentrated sediments from the middle and lower reaches of the Yellow River are normally deposited at the estuary. The nearshore seabed of the Yellow River Delta (YRD) is repeatedly re-deposited and excess pore-water pressure and upward seepage

Citation: Guo, Z.; Hong, Y.; Jeng, D.-S. Structure–Seabed Interactions in Marine Environments. *J. Mar. Sci. Eng.* **2021**, *9*, 972. <https://doi.org/10.3390/jmse9090972>

Received: 30 August 2021

Accepted: 1 September 2021

Published: 7 September 2021

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appear in the newly deposited seabed. Tang et al. [2] reported a series of laboratory experiments carried out on the newly deposited sediments in the Yellow River Delta in their O-tube flume. They focused on the critical hydraulic gradient for seepage failure, which has a significant effect on the erosion and re-suspension of sediments.

Most studies available in the literature focus on the prediction or evaluation of seabed liquefaction under various dynamic loading processes, such as ocean waves, currents, and earthquakes. Measurements of the rheological characteristics of liquefied sediments are limited. Zhang et al. [3] introduced an on-site test device based on the shear column theory. The device was tested in the Yellow River Delta. To verify the field measurements, the authors also conducted a series of laboratory rheological tests. The authors further outlined the applicability of the in situ device in offshore areas.

The construction of a tunnel in the marine environment has attracted much attention from coastal and geotechnical engineers due to the ongoing demands of tunnel construction in coastal cities. To appropriately model the physical properties of coastal sand during the construction of tunnels, Zhu et al. [4] presented a series of experimental results of triaxial compression tests for dry and saturated sand with different initial void ratios. The experimental results were used to modify the disturbance function in terms of the parametric constant (K) and friction angle of the soil (ϕ), utilizing disturbed state concept (DSC) theory. Based on the proposed disturbance function, a modified Duncan–Chang model taking into account construction disturbance was proposed. The developed constitutive framework was further incorporated into the well-known commercial software, ABAQUS, to simulate the ground movement during tunnel construction.

An immersed tunnel may be constructed in a submerged trench. Although the artificial slope is temporary during construction, its stability under wave loading needs to be guaranteed until the end of the construction period. Chen et al. [5] investigated the slope stability of the submerged trench of the immersed tunnel under combined solitary wave and current loading. In their study, the commercial software FLOW-3D was adopted to simulate the solitary wave propagation, and the FEM seabed model was governed by Darcy's flow with the continuity of pressure at the water–seabed interface. The seabed behavior was described by the Mohr–Coulomb constitutive model. The stability of the slope could be calculated by 2D plane strain approximation with the Mohr–Coulomb yield criterion. In their study, they drew the following conclusions. First, as the slope ratio increases, the factor of safety (FOS) decreases. The maximum deformation is likely to concentrate at the bottom of the slope with an increasing slope ratio. Second, when the foundation trench takes the form of a two-stage slope, the slope ratio of the lower slope has a more significant influence on the stability of the whole slope compared with that of the upper slope.

Spudcan foundations have been used to support offshore jack-up platforms, which are extensively used in the offshore industry for drilling and exploration activities. In many previous studies, the "installation effects" are largely disregarded; however, these effects are widely known to affect various aspects of spudcan behavior. Lin et al. [6] re-evaluated the elastic stiffness coefficients of spudcan foundations after the proper consideration of spudcan installation effects using the commercial FEM software, ABAQUS. From this paper, expressions for the dimensionless elastic stiffness coefficient of spudcan are provided. The product of the reduction factor and the elastic stiffness coefficient thus gives the elastic stiffness of spudcan foundations with the consideration of the spudcan installation effects. In practical applications, these coefficients can be directly employed as the boundary conditions in structural analysis for the design of the spudcan.

Pile-type foundations have been used to support various offshore infrastructures, such as platforms, cross-sea bridges, etc. In this paper, Dou et al. [7] attempts to simulate the entire process of steel-pipe pile jacking in saturated fine-grained soil. Based on numerical simulation, it was concluded that during pile installation, the negative excess pore-water pressure near the ground surface around the pile and at a certain depth below the pile tip would increase the effective stress and hence the penetration resistance.

Breakwaters are one of the key nearshore coastal structures used for protection of coastlines. Jeng et al. [8] proposed the use of a mesh-free method for examining the wave-induced soil response around a submerged breakwater. Both regular and irregular wave loadings are considered. This study could be the first attempt at the application of a mesh-free method for the problem of wave-induced seabed response around a breakwater. However, this study is limited in that only the oscillatory soil response and 2D conditions are considered. The further development of the mesh-free model could include extension to 3D and the consideration of the residual soil response in the future.

Offshore pipelines are key marine infrastructures for various purposes, such as the transportation of oil and gas from offshore to onshore regions. Therefore, the damage caused to a pipeline due to seabed instability has been a main concern of offshore pipeline projects. Wu et al. [9] proposes a new fractional cyclic model for capturing the state dependency, non-associativity, and cyclic mobility behavior of sand. The proposed model is validated using two-way stress- and strain-controlled undrained cyclic tests of Karlsruhe fine sand. Then, the model is further adapted for the practical engineering problem of an offshore pipeline fully buried in a trenched layer with different backfilled materials. In their study, second-order Stokes wave theory is used to describe the dynamic wave loading. As reported in this study, the non-associativity of sand has an important effect on the accumulation of wave-induced excess pore pressure and plastic strain. Furthermore, soils at the top of the pipeline are more prone to wave-induced liquefaction than they are at other locations within the seabed. Moreover, a trench layer of non-liquefiable materials with a high permeability is found to be useful for preventing seabed liquefaction in submarine pipelines.

In summary, this Special Issue not only provides information on recent advances in the field of structure–seabed interaction in the marine environment but also highlights scopes for future research in this field. This will light several possible research directions in the field for the readers.

Author Contributions: D.-S.J.: writing—original draft preparation; Z.G.: writing—review and editing; Y.H.: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: The authors are grateful for the support from all authors and reviewers.

Conflicts of Interest: The authors declare no conflicts of interest.

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