Numerical simulation of nonlinear wave-induced seabed response around mono-pile foundation

Yakun Guo[1], Zaibin Lin[2], Dubravka Pokrajac[2], Dong-sheng Jeng[3], Tian Tang[4], Nick Rey[5], Jinhai Zheng[6], Jisheng Zhang[6]

[1]Bradford University (y.guo16@bradford.ac.uk); [2] Aberdeen university; [3] Griffith University; [4] Bekaert Technology Center; [5] Wood Group Kenny; [6] Hohai University

Introduction

Knowledge and understanding of wave-structure-seabed interaction is of particular importance to the design of offshore wind energy devices. Mono-pile foundation supporting offshore wind turbine suffers the damage from waves, while soil near the foundation could be liquefied under wave loading. Both can cause the instability of offshore wind turbine. Understanding these mechanisms and accurate prediction of their influences on mono-pile foundations are therefore particularly important in engineering design.

In this study, a numerical model is developed within the framework of OpenFoam to investigate the wave-structure-seabed interaction. The wave-induced dynamic seabed response and the potential liquefaction around mono-pile is simulated.

Numerical model

Numerical model includes wave model for describing the two-phase incompressible flow field and the seabed model based on the quasi-static Biot's model for describing the wave-induced seabed response (Lin et al 2017). Figure 1 shows the computational domain. The integration procedure of wave and seabed models is as follows:

(1) Applying wave model to solve the Navier-Stokes equations, obtaining dynamic wave pressure.
(2) Using the dynamics wave pressure at the seabed surface from the wave model and applying the seabed model to simulate the wave induced dynamic seabed response.

Computational time step is determined using CFL condition; pressure-velocity coupling is solved by using PISO-SIMPLE algorithm

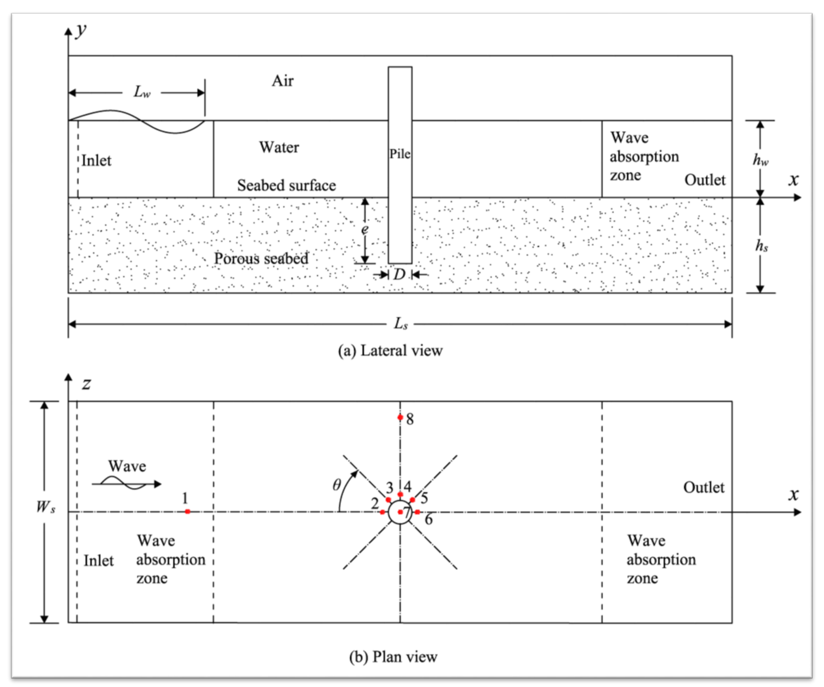

Figure 1 Sketch of computational domain

Validation

Validation is conducted for both the wave model (Figure 2) and seabed model (Figure 3). Figure 2 shows the comparison between the simulated (solid lines) and laboratory measured (closed circles, Zeng et al. 2010) for various input wave heights and periods. Figure 3 compares the simulated (solid line) vertical distribution of the maximum pore water pressure with the laboratory measurements (open triangles) Liu et al. 2015). Both shows good agreement between the simulation and the laboratory experiments. Figure 3 shows that there exists a relatively large deviation between the simulation and experiments at the position close to seabed bottom (y/h_s=-0.8). This may be ascribed to the fact that the soil in the physical test was not perfectly homogeneous (Liu et al. 2015), i.e. soil properties could have been different close to the bottom, while in numerical model soil properties are kept constant.

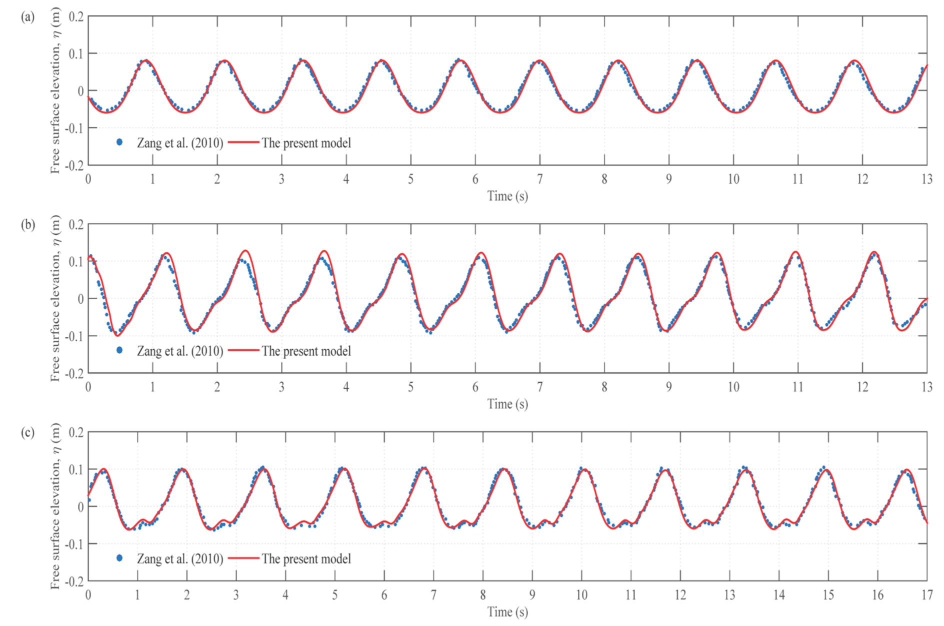

Figure 2Validation of free surface elevation (η) against experimental data (Zang et al., 2010). (a) Wave height H = 0.14 m and period T = 1.22 s, (b) H = 0.14 m and T = 1.22 s, (c) H = 0.12 m and T = 1.63 s.

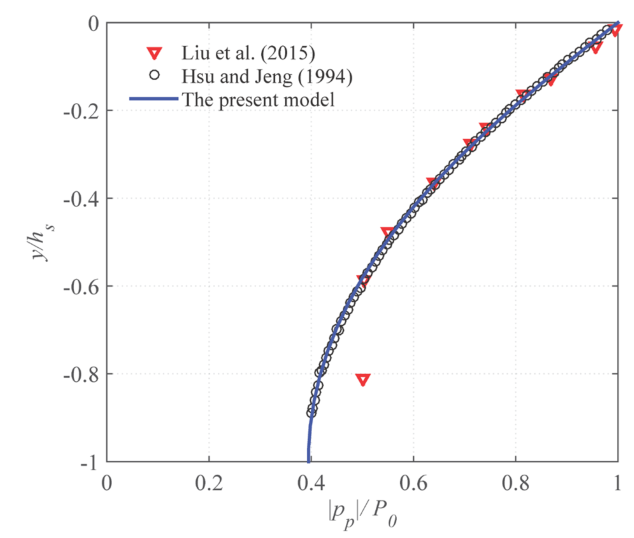

Figure 3 Comparison of simulated and measured (Liu et al. (2015) vertical distribution of the maximum pore water pressure for Sr = 0.996

Results

Validated model is applied to investigate the nonlinear wave induced seabed response around a monopile with various embedment depth. Figure 4 shows the vertical distribution of pore water pressure around pile, located 0.05 m away from the surface of mono-pile with θ ranging from 0° to 180° with 45° increment.

It is seen from Figure 4 that the maximum amplitudes of the vertical pore water pressure are found to appear at the front face of mono-pile foundation, i.e. $\theta=0^0$, while the smallest amplitudes take place at θ = 90°. Between θ=0^0 and θ=90^0, the overall pore water pressures along the embedment depth decrease. Only a small decrease under the pile is seen to take place.

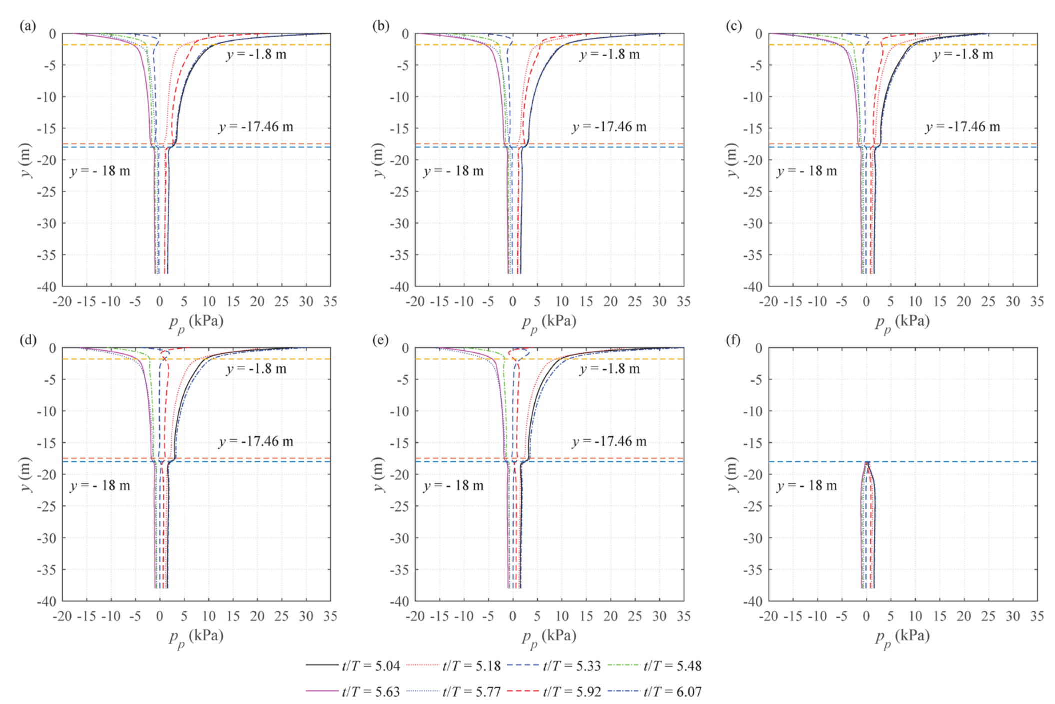

Figure 4 Vertical distribution of pore pressure at θ = (a) 0^0, (b)45^0, (c) 90^0, (d) 135^0, (e) 180^0, and (f) Centre of mono-pile bottom

Figure 5a,b shows momentary liquefaction potential arising as wave trough passing. Figure 5c shows liquefaction depth at the interface between soil and foundation. Liquefaction depth gradually increases from the front of pile and reaches the maximum at θ = 90^0, and slightly decrease with the increase of θ. Figure 5d is temporal evolution of the liquefaction depth at several θ-locations. Figure 6 shows that embedment depth has insignificant effect on liquefaction depth at the front face of mono-pile foundation and liquefaction depth decreases with the increase of embedment depth. This may be ascribed to the fact that increasing embedment depth has blocking effect on the pore water pressure propagation from front to back of mono-pile, which decreases the difference of pore water pressure along the embedment depth and leads to smaller liquefaction depth.

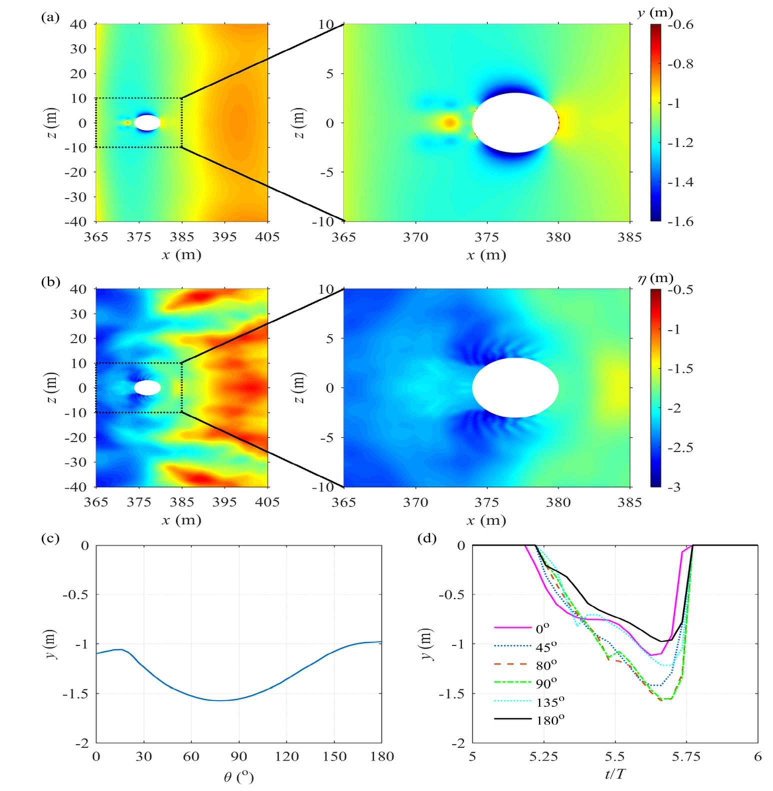

Figure 5 Liquefaction depth (y) and free surface elevation (η) around mono-pile foundation at t/T = 5.66. Contour plot of (a) y, (b) (η), (c) y at the soil-pile interface, (d) time series of y at various θ-locations on the soil-pile interface.

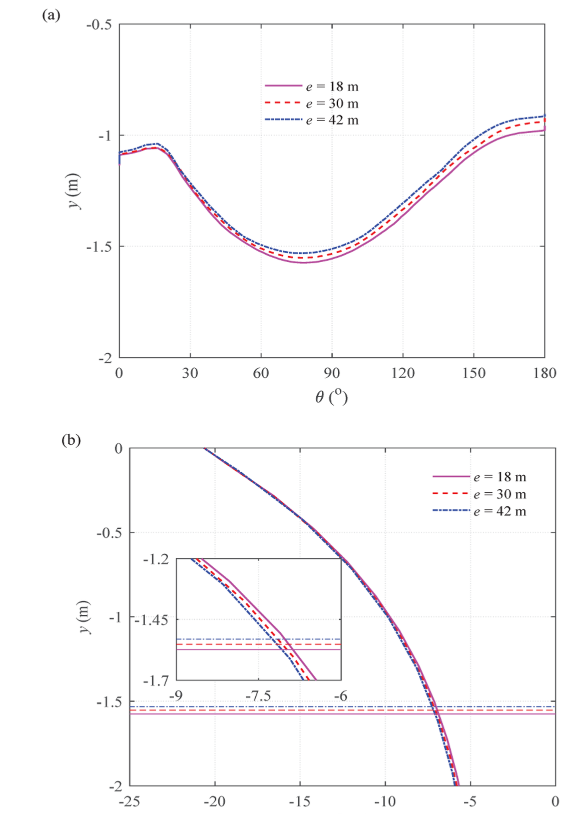

Figure 6 Variation of liquefaction depth y with embedment depths at t/T = 5.66. (a) Variation of y with θ on the soil-pile interface, (b) y at θ =90^0, horizontal lines are the maximum liquefaction depth.

Conclusions

In this study, we investigate the nonlinear wave-mono-pile-seabed interaction using the integrated wave-soil models. Wave-induced dynamic seabed response around mono-pile has been simulated. Potential momentary liquefaction around mono-pile foundation has been estimated using the liquefaction criteria of Sumer (2014). Effect of embedment depth of mono-pile on the liquefaction depth has been simulated. Results show that (1) wave-induced pore pressure decreases with the increase of soil depth; (2) the difference between the pressure at seabed surface and the pore pressure generates an upward force resulting in the momentary liquefaction around mono-pile foundation; (3) Increasing embedment depth of mono-pile will greatly reduce the pore pressure along the embedded foundation, thus reduce the liquefaction depth.

Acknowledgments

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