Assessment of wave-induced momentary seabed liquefaction

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ABSTRACT
Seepage force induced by ocean waves has been related to the liquefaction around submarine structure, and it has been shown to cause significant sediment transport and rapid burial of pipelines and objects (Tsai et al., 2022). This study assesses the impact of momentary soil liquefaction due to pore pressure gradient near seabed generated by waves in the range of oceanic and coastal environment. The nonlinear wave solution of the stream function numerical approximation is applied to cover the wide range of wave condition in ocean and to evaluate the contribution of kinetic term in the energy equilibrium of water waves, which appears at least in third order analytical solution. The dispersion relation for coupled wave-soil interaction is discussed to shed insight on the effect of seabed response on wave dissipation. The present solution demonstrates the momentary liquefaction near mud line, which is triggered by the pore pressure gradient under wave trough and assesses the trigger criterion of wave condition in wave-current environment.

METHODOLOGY
Based on Biot's consolidation theory, an analytical solution of seabed response under water waves for poroelastic media is presented, and the solution of pore pressure, which drives seepage movements, is verified with laboratory experiments. The generalized seabed response under an anisotropic permeability is solved as an eigenvalue problem, and the bottom pressure fluctuation of water waves calculated by steady wave theory for ideal flow acts on mud line as an input loading of wave-soil interaction. Utilizing the harmonic solution of seabed response for linear wave, the bottom pressure of nonlinear waves is expanded as Fourier series so as to behave the corresponding seabed response through superposition principle.

RESULTS
Figure 1 shows the characteristic of liquefaction zone where vertical pressure gradient force lifts sediment grains near seabed surface is investigated in scenarios to sketch the critical wave condition triggering sediment suspension. The trigger criteria of wave condition are presented in a parametric map. In this study, advanced wave theory at lease third order solution is necessary to capture the effect of wave asymmetry contributed by kinetic energy equilibrium. According to the study of critical wave condition, the effect of wave nonlinearity is importance in particularly for shallow water waves. On the other hand, the prediction of present solution is closed to the prediction based on linear wave theory for intermediate and deep water waves.

This study shows the importance of saturation and permeability on the building up of pressure gradient and the occurrence of seabed instability. Seabed has a potential risk of momentary liquefaction for low permeability and the presence of air content, which both amplifies the pore pressure dissipation. We find that there is low possibility of liquefaction on fully saturated sediments for nonlinear wave case. The nonlinear wave model corrects the criteria for long wave. The nonlinearity of wave decreases the possibility to liquefaction for shallow water wave. On the other hand, the presence of air content increases the risk.

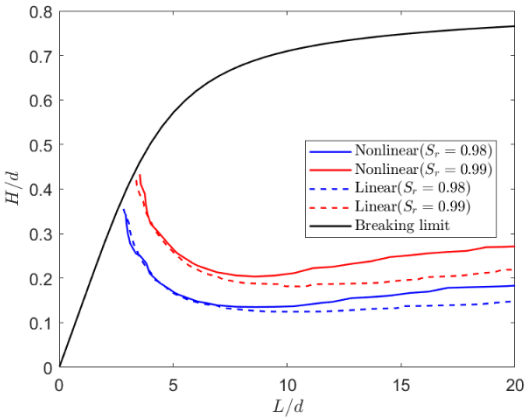

Figure 1 - Effect of seabed saturation on trigger criterion of wave conditions.

REFERENCES
Tsai, Mathieu, Montellà, Hsu, Chauchat (2022): An Eulerian two-phase flow model investigation on scour onset and backfill of a 2D pipeline, European Journal of Mechanics-B/Fluids, ELSEVIER, vol. 91, pp. 10-26.