Combined wave-current induced oscillatory seabed responses around two pipelines in tandem

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ABSTRACT
The seabed stability in the vicinity of submarine pipelines under wave-plus-current conditions is one of the major issues in offshore projects. Previous works mainly focus on the evaluation of the seabed response around a single pipeline. In this study, the previous model (PORO-FSSI-FOAM) will be adopted to investigate the effect of the gap ratios \((G/D)\) of twin pipes on the wave & current-induced transient seabed response. Based on numerical examples, the following conclusions were found: (i) the effect of different \(G/D\) between twin pipes on the distribution of excess pore-water pressure and resulting seabed liquefaction cannot always be ignored; and (ii) as the gap ratio \((G/D)\) is 1.25, the soil response beneath both pipelines is significant than in the condition of a single pipeline.

KEY WORDS: pipelines in tandem; excess pore-water pressure; horizontal distance between twin pipes; OpenFOAM; seabed liquefaction; 2D model

INTRODUCTION
Pipelines are one of the essential installations for the oil and gas industry, which have been used for the transportation of oil and gas from offshore to onshore. Since the first offshore pipeline was built by Brown Root to carry oil in 1954, the development of the submarine pipeline networks has across the globe, even were regarded as “lifelines” of the oil industry (Sumer and Fredsøe, 2002). The existence of the submarine pipeline does not only alter the nearby flow morphology but also lead to the surrounding seafloor instability (including soil liquefaction, scour and shear failure) and ultimately cause damage or failure of the pipeline (Sumer, 2014). In general, when the seabed is exposed to the wave, the generated dynamic pressures along the seafloor can induce the pore pressures, effective stresses and soil displacements within the seabed (Jeng, 2012). Then, the seabed in the vicinity of the pipeline could become unstable or even liquefied due to the increasing excess pore pressures and the reducing vertical effective stresses. Once the liquefaction occurs, the soil will behave like a kind of heavy fluid without any shear resistance, which greatly enhances the risk for the pipeline to sag.

Two categories associated with the mechanisms of wave-induced seabed liquefaction have been identified (Zen and Yamazaki, 1990; Nago et al., 1993): oscillatory and residual liquefaction, which are in accordance with the generated procedure of pore water pressure. The oscillatory liquefaction normally appears instantaneously under wave troughs in very dense sand deposits with linear reversible soil characteristics, which is related to phase lag and amplitude decay in the oscillatory pore pressures (Madsen, 1978). The residual liquefaction is generally caused by the build-up of the excess pore pressure under the volumetric wave loading, which is usually observed within the fully saturated seabed (Seed and Rahman, 1978; Sumer, 2014). In this study, only the oscillatory liquefaction mechanism with transient pore pressure is examined.

Based on Biot’s poro-elastic theory (Biot, 1941), numerous numerical studies for the Wave-Seabed-Structure Interactions (WSSI) have been available in the literature. Among these, Jeng and Cheng (2000) proposed an FDM model to discuss the possibility of wave-driven shear failure around a pipeline. They found that as the burial depth and pipe radius increased, the potential shear failure around a pipeline rises in the seabed with a lower degree of saturation. A few FEM studies have been implemented to explore the wave-induced seabed responses around a buried or trenched pipeline (Gao et al., 2003; Gao and Wu, 2006; Zhang et al., 2011). However, the aforementioned investigations have not considered the combined loadings of waves and currents. Liang et al. (2020) proposed an OpenFOAM model to study the mechanism of soil response and liquefaction induced by the combined waves and currents. In their research, they pointed out the liquefaction phenomenon was easier to observe around the inlet of the currents.

Due to technical and economic factors, two pipelines are occasionally laid in parallel. In the existing design method, the two tandem pipelines were processed individually because of the large gap between them in practice. However, Li et al. (2020) revealed the twin pipes become more dependent with decreasing horizontal distance, which means that it is not reasonable to treat them separately. The previous research related to the two pipelines that are laid in parallel mainly focus on the local scour under different flow conditions. For example, Zhao et al. (2015) investigated the scour around the twin pipelines under steady current and various pipeline gap conditions. The numerical results