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Dynamic response of a porous seabed around pipeline under three-dimensional wave loading

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ABSTRACT

The evaluation of the wave-induced pore pressure around a buried pipeline is particularly important for pipeline engineers involved in the design of offshore pipelines. Most previous investigations of the wave-induced dynamic response around an offshore pipeline have limited to two-dimensional cases. In this paper, a three-dimensional model including buried pipeline is established, based on the existing DYNE3WAC models. Based on the proposed numerical model and poro-elastic soil material assumption, the effects of wave and soil characteristics, such as wave period, water depth, shear modulus and permeability, and configuration of pipelines, such as pipeline radius and pipeline buried depth, on the wave-induced excess pore pressure will be examined. Numerical results indicated that the normalized excess pore pressures versus z/h near the pipeline increase as the obliquity angle, wave period and water depth increase, and they decrease as the burial depth and radius of pipeline increase above the pipeline. Soil permeability has obvious influence on the wave-induced normalized excess pore pressure, and different soil material will result in distinct computation results.

1. Introduction

Gravity waves propagating over the ocean exert dynamic pressure fluctuations on the sea floor. These fluctuations further exert effective stresses and excess pore pressure within the soil skeleton, which have been recognized as dominant factors in analyzing the instability of a seabed. When the pore pressure becomes excessive with accompanying decrease in effective stress, a sedimentary bed may be moved in either horizontal (liquefaction) or vertical directions (shear failure), then lead to an instability of the seabed [1,2]. It has also been reported that the soil supporting the pipeline may fail due to liquefaction, resulting in the self-burial of the entire pipeline [3,4].

Numerous investigations for the wave-induced seabed response have been carried out since the 1970s. Among these, analytical approximations have been developed by various researchers such as Madsen [5], Yamamoto et al. [6], Mei and Foda [7] and Jeng [8]. Numerical simulations also have been widely applied to examine such a problem in recent years. Cheng and Liu [9] considered a buried pipeline in a region that is surrounded by two impermeable walls. Magda [10] considered a similar case with a wider range of degree of saturation. Luan [11] considered soil–pipeline contact effects and inertial forces in a new model. At the same time, experimental work has attracted attention from researcher and pipeline engineers. Summer et al. [4] and Teh [12] are the two recent contributions to the problem of the on-bottom stability of marine pipelines on liquefied seabed.

However, the majority research of numerical models about submarine pipeline is limited to two-dimension cases, in which the wave approaches normal to the orientation of pipeline. However, in the real ocean environment wave may approach the pipeline from any direction. Therefore, it is necessary to establish a three-dimensional model to study these realistic circumstances under an oblique wave loading.

Among available investigations, Chen et al. [13] proposed a three-dimension model by using the consolidation equations of Biot, it was concluded that there is no difference between two-dimensional and three-dimensional cases. In another investigation, Shabani and Jeng [14] developed a three-dimensional numerical model to analyze the behavior of soil around pipeline under the wave loading, in which finite element analysis software Comsol Multiphysics was used.

To further investigate dynamic response of three-dimensional model under wave loading, a finite element program DYNE3WAC

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