Ocean Engineering 139 (2017) 116–126

Contents lists available at ScienceDirect

Ocean Engineering

journal homepage: www.elsevier.com/locate/oceaneng

Dynamic vertical impedance of a submarine strip foundation in ocean engineering: Water wave pressure effect

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ARTICLE INFO

Keywords:
Strip foundation
Vertical dynamic impedance
Water wave pressure effect

ABSTRACT

Many papers in the literature present studies of the interaction of sea waves, structures, and soil; however, most of these studies focus on the pore pressures and stresses in the soil around structures. Very little knowledge has been obtained regarding the impedance of a foundation considering the coupling of the water wave pressure effect (WPE) and dynamic soil-structure interaction (DSSI), as classical impedance functions are obtained based on a foundation on an elastic half-space with a stress-free surface. Impedance functions can be used to study the dynamic responses of a structure using the substructure method during the serviceability limit state design. This paper studies the forced vertical vibration of a strip foundation on a poro-elastic seabed with surface subjected to water wave pressures. The strip foundation on the seabed is simultaneously excited by water wave and other external forces at the same frequencies as water waves (with WPE-DSSI coupled). Three new impedance functions for foundations in ocean engineering are defined. Selected results for the new impedance functions are examined based on different water depth, wave height, wave frequency, and poroelastic material. The results show that for a rigid strip foundation in ocean engineering, both its total impedance and effective impedance are displacement dependent.

1. Introduction

Dynamic problems of strip foundation-soil interactions in offshore geotechnical engineering are very important in the design of foundations and pipelines. The obtained elastic impedance of a strip foundation can be used to model the pipeline-soil interaction (Fig. 1a) (Guha et al., 2016), the settlement of a submerged breakwater (Fig. 1b), and the dynamic responses of a floating structure (Fig. 1c) using the "substructure method" widely accepted in structure dynamics (Clough and Penzien, 2003). However, almost all existing impedance models for a strip foundation are based on the vibration of a rigid strip on an elastic half space with a stress-free surface (Fig. 2a), which has been studied by many researchers: Karasudhi et al. (1968), Oien (1971), and Luco and Westmann (1972) analyzed the vibration of a rigid strip footing vibrating on an elastic half space using integral equations methods; Spyrakos and Beskos (1986) studied the rigid strip foundations on a linear elastic half-space subjected to time varying external forces numerically. Kassir and Xu (1988) conducted a study of a rigid permeable strip footing in contact with a two-phase poroelastic half-space. Halpern and Christiano (1986) studied the dynamic responses of a rigid plate resting on a saturated half space. Cai et al. (2008) studied the vertical vibration of an elastic strip footing on saturated soil.

However, although almost all offshore foundations and pipelines operate underwater, very few papers consider how the presence of water affects the dynamic impedance of a foundation. To the best of the authors' knowledge, the only relevant work is the report of He et al. (2012), who presented an analytic method to study how the existence of still water affects the impedance of a disc (Fig. 2b), which is only suitable for foundations in seas with negligible water wave pressures. The goal of this work is to investigate the dynamic impedance of a strip foundation on a poroelastic soil surface subjected to water wave pressures (Fig. 2c). The process by which the impedance is influenced by the coupling of the WPE and DSSI will be studied in detail below. The governing equations of the problem are obtained using Biot's theory and the proper boundary conditions at the foundation-soil interface. Using the integral equation approach and Chebyshev polynomials, the governing equations are expressed in terms of dual integral equations that are converted into Fredholm integral equations and then solved numerically.

Note that the study in this paper is quite different from the widely studied wave-induced seabed stability problem, which focuses on wave-induced forces on pipes or stresses and pore pressures in the soil around pipelines or breakwaters subjected to sea waves (Hsu and Jeng, 1996; Jeng et al., 2001; Jeng and Cheng, 1999; Kumagai and Foda, 2001; Lennon, 2010; Magda, 2000; Magda and Magda, 1997; Mase

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http://dx.doi.org/10.1016/j.oceaneng.2017.04.028
Received 30 May 2016; Received in revised form 4 December 2016; Accepted 20 April 2017

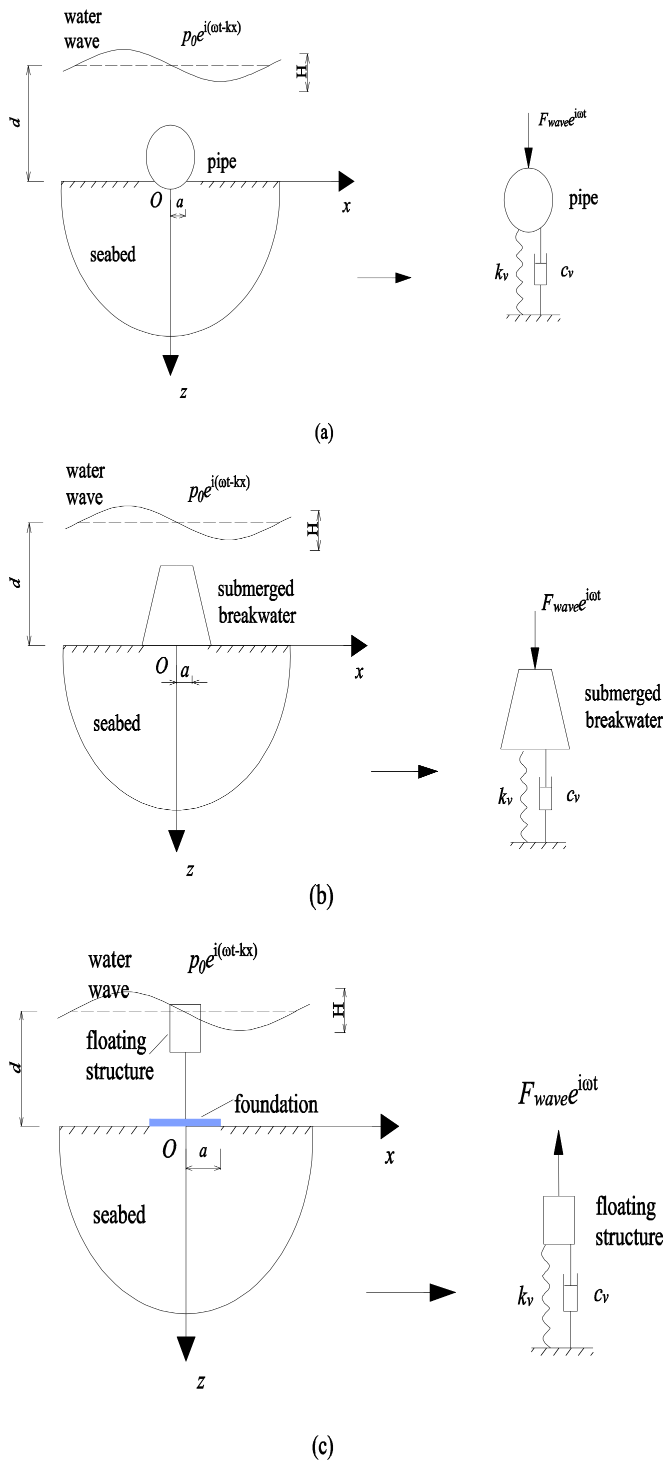

Fig. 1. Three simplified foundation–soil interaction models: (a) simplified pipe-soil interaction model; (b) simplified breakwater-soil interaction model; (c) simplified floating structure-soil interaction model.

et al., 1994; Mei and Foda, 1981; Sudhan et al., 2002). Most of these studies ignored DSSI by considering the structure and the soil as being static or quasi-static; in addition, no foundation impedance information was given, and the coupling of WWP and DSSI was still not considered. In summary, most of the existing studies related to sea waves, structures and soils focused on the wave-induced soil responses around the structures, and no report has considered how sea waves will change the impedance of a foundation within the classical elastodynamics. This study focused mainly on the impedance of a strip, the

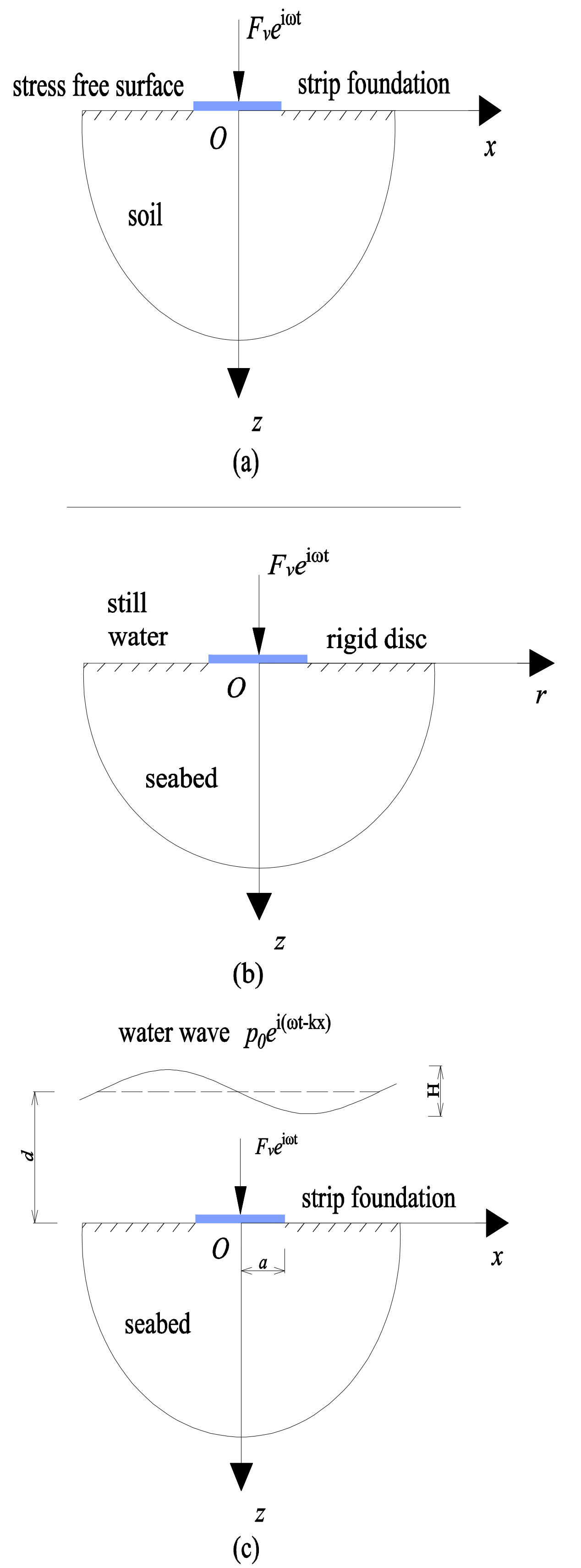

Fig. 2. Three different foundation vibration models: (a) a strip foundation vibrating on a soil half-space with a stress-free surface; (b) a disc foundation vibrating on a soil half-space under still water; (c) a strip foundation vibrating on a soil half-space with water wave pressures on the surface.