Porous Models for Wave-seabed Interactions

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Chapter 1
Introduction

Abstract In this chapter, the background and importance of marine geotechnics with an emphasis on the phenomenon of wave-seabed interactions and its application are outlined. Several hot topics in this area are also suggested for future research development.

Keywords Marine geotechnics · Porous flow · Wave-seabed interactions

1.1 Introduction

When a coastal structure is installed in marine environments, the presence of the structure will alter the flow patterns in its immediate neighborhood. The flow condition around the structure does not only affect the wave force acting on the structure, but also induce sea floor instability. The former one has been the main concern in the design of coastal structures, which has been intensively studied by coastal and structural engineers. However, the latter involves the foundations of the structure, which has attracted attention from coastal geotechnical engineers in recent years.

In the past few decades, considerable efforts have been devoted to the phenomenon of the wave–soil–structure interactions. The major reason for the growing interest is that many coastal structures (such as vertical walls, caissons, offshore mono-piles and pipelines, etc.) have been damaged by the wave-induced seabed response, rather than from construction deficiencies [9, 13, 21]. It is common to observe that concrete armor blocks at the toes of many marine structures have been found to subside into the seabed. Wave-induced liquefaction and shear failure have been identified as culprit for this problem [19]. Another reason is that the poro-elastic theories for wave-soil interaction have been applied to field measurements, such as the determination of the shear modulus of soil [24] and the directional spectra of ocean surface waves [15], as well as acoustic wave propagating through porous media [25].

When water waves propagate in the ocean, they generate significant dynamic pressures on the sea floor. This pressure field induces pore water pressure and effective stresses within the seabed. With excess pore-pressure and diminishing vertical effective stress, part of the seabed may become unstable or even liquefied. Once

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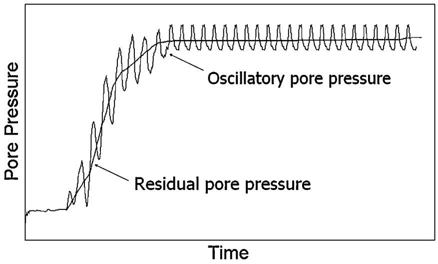

Fig. 1.1 Conceptual sketch of two different mechanisms of pore pressure (not in scale)

liquefaction occurs, the soil particles are likely to be carried away as a fluid by any prevailing bottom current or mass transport owing to the action of ocean waves.

Generally speaking, two mechanisms of the wave-induced soil response have been observed in the laboratory and field measurements, depending on the manner that the pore pressure is generated, as illustrated in Fig. 1.1 [14, 26, 27]. One is caused by the progressive nature of the excess pore pressure, which appears at the initial stage of cyclic loading. The other is generated by the oscillatory pore pressure, which is accompanied by the amplitude damping and phase lag in the pore pressure. This type of soil response appears periodically during a storm sequence. In most marine sediments, the wave-induced soil response is oscillatory in nature, except for some special cases of non-cohesive sediments with loose to medium density [18].

The occurrence of seabed instability is a widespread phenomenon in ocean environments [20]. There is evidence of ocean floor instability in a wide variety of offshore regions, from shallow water, near-shore zones, continental slopes and beyond to deep ocean floors. Seabed instability has been responsible for the damage and destruction of offshore structures [2, 3, 9].

Many variables affect the wave-induced soil response in a porous seabed. One of them is the soil permeability, which is a measure of how rapidly fluid is transmitted through voids between grains. Marine sediments below the water-seabed interface undergo consolidation owing to both the overburden soil pressure and the water pressure above it. This will result in a decrease in void ratio and porosity, accompanied by an increase in specific gravity of the soil. An example of the soil permeability varying with buried depth (z) was reported by [8] for marine sediments in the Gulf of Mexico. Similar evidence for soil consolidation versus depth has also been reported in the literature [4, 5, 17].

Shear modulus is another important parameter in determining the wave-induced soil response. It is a proportionality coefficient in shear stress-shear strain relationship. For the consolidation problem, the medium whose shear modulus increases linearly with depth, called *Gibson Soil*, has been studied [7, 10]. In fact, the rigidity of soil in a natural seabed generally increases with depth as a consequence of the increasing effective overburden pressure. Some evidence for the shear modulus of soils varying strongly with depth has been reported [1, 12, 22].

In reality, most marine sediments display certain degrees of anisotropy, having different elastic properties in the vertical and horizontal directions. This is caused by the manner of their deposition, particular grain shapes and stress history. However, many materials show more limited forms of anisotropy. For example, a material having the same properties in any horizontal direction but different in the vertical direction is referred to as cross-anisotropy [16]. When a material is deposited vertically and then subjected to uniform horizontal stress, it is expected to exhibit a vertical axis of symmetry and then be transversely isotropic [11]. It is noted that the anisotropical soil behavior discussed here is the mechanical behavior due to change of stress. There can also be anisotropy in permeability and variability in porosity.

A natural seabed normally consists of multiple layers in which different soil properties exist in each layer. For instance, the sediment in the Ekofisk oil field in North Sea has an upper layer about 75 m, consisting of a mixture of sand and clay. Below this, a clay layer was observed [6]. Moreover, it is common to place concrete armor blocks or gravel on the seabed at the toes of marine structures, in order to protect the seabed. In recent years, some marine geotechnical engineers have even suggested pre-mixing or replacing part of the seabed sediment by coarser materials to minimize the effect of wave-induced liquefaction [23]. Thus, it is obvious that the soil column has to be treated as a multi-layered medium in both natural and artificial seabed. However, the effects of a cover layer on the wave-induced soil response and seabed instability have rarely been investigated in engineering applications.

To date, non-homogeneous soil characteristics (either variable soil characteristics or multi-layered) and anisotropic soil behavior have been considered in existing poro-elastic models for the wave-induced seabed response. The relevant studies will be reviewed in latter sections.

Although the phenomenon of wave-induced seabed instability has received great attention among coastal and geotechnical engineers since 1980's, preliminary experiments and theories for such a problem have only been available for two-dimensional progressive waves. Recently, significant progress has been made towards the development of both analytical and numerical approaches for some simple modes of instability in the vicinity of marine structures. However, to date, a systemic review on the development of the sea floor dynamics in the vicinity of coastal structure, providing a research guide for coastal geotechnical engineers, has not been available.

1.2 Hot Research Topics

In the area of marine geotechnical engineering, despiting the recent developments, in the author's opinion, more intensive and advanced researches are desired in the following two topics:

- Most existing models for wave-seabed interactions have been based on the constitutive models used in onshore geotechnical engineering. However, a nature seabed is under a much complicated environmental loadings such as wave, current and seismic loadings. Furthermore, the seabed in normally under seawater. The question arising is that whether the existing constitutive relations can be applied to offshore environments or not. To date, an appropriate soil constitutive model for marine geotechnical engineering is still not available in the public literature.

- Most previous studies for wave-seabed interactions have been limited to uncoupled approached or so-called integrated model, rather than a fully coupling models. In fact, the seabed properties are changed by environmental loadings as well as they will affect the environmental loading. Most existing studies have considered the former mechanism, but ignore the latter one. Although the influence of seabed characteristics on the environmental loading may not be significant, however, without n appropriate approach, its effects are unknown and may underestimate the seabed instability.

In addition to the above fundamental issues in the areas of wave-seabed interactions, the applications of the porous models to another practical engineering issue, wave-seabed-structure interaction, is also a vital problem in the file dof marine geotechnics.

1.3 Outline of the Book

The present book is an attempt to give a comprehensive account of wave-seabed interaction around marine structure. It also takes into consideration all state-of-the art knowledge. We shall start off with the literature review (Chap. 2). These include a detailed review and summary of existing work. Next, we shall concentrate on the mathematical models of wave-induced soil response in an isotropic and homogeneous seabed (Chaps. 3 and 4), which will be followed bytheoretical models for a seabed of variable soil characteristics and soil behavior (Chap. 5). In Chaps. 6 and 7, dynamic soil behavior and Coulomb-damping effects are considered and the applicable ranges of dynamic models are clarified. Then, random wave-induced seabed response in marine sediments with two commonly used wave spectra is explored in Chap. 8. In Chap. 9, the mechanism of pore pressure accumulation (pore pressure build-up) and its analytical solution are discussed. Finally, the process of the wave-induced post-liquefaction (progressive liquefaction) is clarified in Chap. 10.

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