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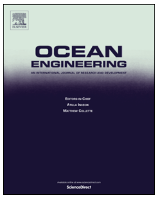

Dynamic response analysis of a floating offshore structure subjected to the hydrodynamic pressures induced from seaquakes

Jin Ho Lee [a,*], Jae Kwan Kim [b,c]

[a] Maglev Train Research Team, New Transportation Systems Research Center, Korea Railroad Research Institute, 176 Cheoldo bangmulgwan-ro, Uiwang-city, Gyeonggi-do 437-757, Republic of Korea
[b] Department of Civil and Environmental Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul 151-742, Republic of Korea
[c] Integrated Research Institute of Construction and Environmental Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, 151-742, Republic of Korea

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ABSTRACT

A seismic analysis method for a floating offshore structure subjected to the hydrodynamic pressures induced from seaquakes is developed. The hydrodynamic pressure exerted on the structure by the ocean water, modeled as compressible non-viscous ideal fluid, is calculated taking into account the fluid–structure interaction, the energy absorption by the seabed, and the energy radiation into infinity. From the hydrodynamic pressure, the added mass and the effective load, resulting from the hydrodynamic pressure, are obtained. They are combined with the finite element model of the structure, resulting in a numerical model for the entire coupled system. For validation of the numerical model, the hydrodynamic pressures induced by the vertical motion of the seabed at free field, and due to the vertical vibration of a floating massless rigid disk, are calculated and compared with exact analytical solutions. The developed method is applied to seismic analysis of a simplified support structure for floating offshore wind turbines subjected to the hydrodynamic pressures induced from seaquakes. Analysis results show that dynamic response of a floating offshore structure induced by the vertical seismic motion of the ocean bed can be greatly influenced by the compressibility of sea water and the energy absorption capacity of the seabed.

1. Introduction

The vastness of oceans offers many possibilities that can help sustain human life on earth. The demand for clean energy such as ocean wave energy and wind energy is increasing globally. Traditionally many offshore structures have been built to develop natural resource on or under the sea. Additionally, very large floating structures can serve as artificial islands or extensions of land that may be used to supplement insufficient residential space at regions for which real estate is a very scarce commodity. As a result, it is expected that the demand for offshore structures will continue increasing at a more rapid pace in the future. However these offshore structures should be able to withstand the dynamic effects of environmental loads during their lifetime. These loads range from temporary/transient loads induced by earthquakes and sea storms to continuous (or stationary) loads due to wind, wave, and sea currents, among others. To design and construct offshore structures, including floating ones, against various environmental loads, first we have to understand the response of structures to these loads.

Since floating offshore structures are not supported directly by the ground, however, effects of earthquakes on floating structures have received less attention compared with those on fixed structures. Consequently their seismic response has not been thoroughly studied yet.

Hazards associated with seaquakes are excessive hydrodynamic pressure, tsunamis, and landslides (Gerwick, 2007). Excessive hydrodynamic pressure can occur due to the interaction between the ocean floor and the overlying ocean water, and may cause severe damages to ships and marine structures. Recently, it was recognized that the damage of ships, originally attributed to an undetermined cause, may now be attributed to hydrodynamic pressure induced by seaquakes (Ambraseys, 1985; Hove et al., 1982). One typical example is the case of the motor tanker ‘Ida Knudsen’. Apparently it was damaged severely by a seaquake. Ambraseys argued convincingly that her damage could be explained by a predominantly vertical motion of the sea bottom from a seaquake (Ambraseys, 1985). Hence, a due consideration to earthquake shaking hazard is required when designing and constructing an offshore structure of the floating type in a high seismicity region. Furthermore, a thorough understanding is

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* Corresponding author. Tel.: +82 31 460 5697; fax: +82 31 460 5023.
E-mail address: ohnij2@krri.re.kr (J.H. Lee).

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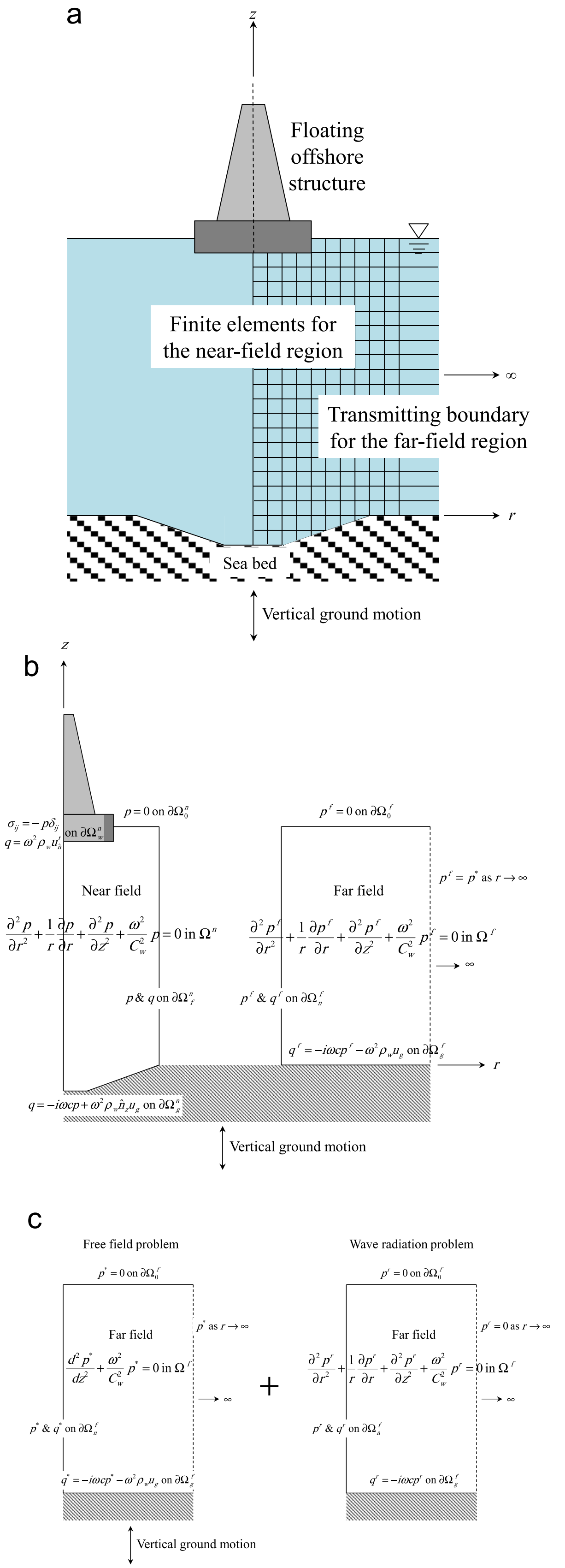

Fig. 1. Floating offshore structure. (a) Schematic view, (b) near- and far-field regions of fluid, and (c) free-field and wave-radiation problems for a far-field region of fluid.

necessary of the associated phenomena and underlying mechanics. It turns out that for seaquakes, a very important consideration is the role of the compressibility of fluid/seawater. As it was noticed in the analysis of earthquake response characteristics of concrete gravity dams (which is another problem where fluid–structure interaction is involved), the compressibility of water can greatly increase the hydrodynamic pressure (Chopra, 1988; Fenves and Chopra, 1983, 1985). In the case of vertical motion of the ocean bottom, it is demonstrated that this pressure amplification is even more pronounced. A floating offshore structure is a fluid–structure interaction system of which the dynamic response can be strongly amplified as a consequence. Hence, the effects of the compressibility of fluid and the vertical motion of the ocean floor must be considered rigorously in earthquake response analysis of a floating offshore structure.

In this study, a seismic analysis method is developed for a floating offshore structure subjected to the hydrodynamic pressures induced from seaquakes considering rigorously the fluid–structure interaction. Fig. 1a shows a schematic view of a floating offshore structure system under consideration. Using the finite-element approach, the mass, damping, stiffness, and hydrostatic stiffness matrices for the structure are constructed. The structure includes the sub-structure for floating as well as the super-structure. The seawater is idealized as a compressible non-viscous ideal fluid. Hydrodynamic pressure on the structure is calculated with careful consideration of the energy absorption capacity of the seabed as well as the energy radiation to infinity. Finite elements and a transmitting boundary for the fluid are employed to calculate the hydrodynamic pressure. The near-field region of the fluid which may have an irregular geometry is modeled with finite elements. On the other hand, the region at far-field which extends infinitely in a radial direction with a constant depth is represented by a transmitting boundary in order to model the energy radiation rigorously. The added mass and the effective load, resulting from the hydrodynamic pressure of the fluid, are calculated from the numerical model with careful consideration of the fluid–structure interaction. They are combined with the finite elements of the structure rendering a numerical model of the entire system. The newly developed method is applied to the seismic analysis of a floating offshore structure subjected to the hydrodynamic pressures induced by the vertical motion of the ocean floor. The effects of the fluid compressibility and the energy absorption capacity of the seabed on the dynamic response of a floating offshore structure are examined.

2. Equation of motion for a floating offshore structure

In Sections 2 and 3, numerical models of components of the fluid–structure interaction system are described in detail. An equation of motion for the entire fluid–structure interaction system is derived in Section 4.

In this study, the structure is assumed to be axisymmetric. Thus its equation of motion is stated in a cylindrical coordinate system in which all physical quantities can be expressed as symmetric or anti-symmetric components. They are either symmetric or anti-symmetric with respect to the plane $\theta = 0$ in the circumferential direction and vary as the $\cos n\theta (n = 0, 1, 2, \cdots)$ or $\sin n\theta (n = 1, 2, \cdots)$ functions. Since in this study only the effects of a vertical motion of the ocean floor by vertically incident seismic waves is considered, only the component with $n = 0$ is considered in the following formulation. The motion of a general three-dimensional system can be described if all components are taken into account. The vertically incident seismic waves have wavenumbers of zero value. Normally, the seabed has an S-wave velocity profile increasing with depth. Then, Snell's law (Aki and Richards, 2002) says that the direction of propagation of incident