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The prediction of the dynamic and structural motions of a floating-pier system in waves

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Abstract

In this study, a two-dimensional floating pier consists of single rectangular impermeable pontoon with side supporting pile-columns is studied. The purpose of this study is to present a theoretical solution for the linearized problem of incident waves exerting on a floating pier with pile-restrained. All boundary conditions are linearized in the problem, which is incorporated into a scattering problem and radiation problem with unit displacement. The method of separation of variables is used to solve for velocity potentials. For the radiation problem with unit heave and pitch amplitude, the boundary value problem with non-homogeneous boundary condition beneath the structure is solved by using a solution scheme. By calculating the wave force from velocity potential and solving the equation of motion of the floating structure simultaneously a close form theoretical solution for the problem is developed. The finite element method was also applied to calculate the dynamic responses on the supporting piles subjected to the pontoon motions and incident waves.

Keywords: Floating-pier; Wave structure interaction; Wave force; Pier with guide-pile; Dynamic response

1. Introduction

This paper provides an analytical study for the responses of a floating pier structural system confined horizontally with pile-columns. Floating pier structural system by using semi-submerged buoyant pontoons providing vertical supports for the deck is a widely used structural system because it is easy to construct and convenient to use for offshore deep water application. In the floating pier structural system the pontoon-pier is either anchored by the tension legs to the seabed or supported by pile-columns on the sides for the so-called bridge type floating pier system. The pile-columns not only work as an anchoring system but also provide a confinement to the pontoon-pier from moving around. A complete study for the dynamic behavior of a floating pier structural system is rather complicated, particularly in analytical methods because the analysis must account for not only the interactions between the structure (pontoon-pier) and the waves, but also the interactions between waves, pontoon-pier and the anchoring systems.

The interactions between the floating structure and the incident waves are the well-known scattering problem incorporated with radiation problem. In 1969, Black and Mei first studied the reflection and transmission of waves encountering the floating structure and identified it as a scattering problem. Later on Black et al. (1971) then studied a moving floating structure making waves in the flow field that was identified as a radiation problem. However, to solve these two problems simultaneously the nonlinearity of structural motion and the non-homogeneous boundary conditions on the free surface and on the structural bottom (Garrison, 1974) must be overcome first. This problem has been solved in numerical methods since the 1970s (Mei, 1978; Yamamoto et al., 1982), and also studied through experimental testing (Yamamoto et al., 1982) until Sarpakaya and Isaacson (1981) linearized the boundary conditions. By using the scheme to linearize the boundary conditions, the close form theoretical solution could be obtained by incorporating the scattering problem with the radiation problem.

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To examine the dynamic motion of floating pier structural system, besides the interactions between the structure (pontoon-pier) and waves the behavior of anchoring system, either a tension-leg or supporting pile-column for the pier is also essential. The other problem is that most analytical studies on the interactions between floating structure and waves incorporating with both the scattering problem and radiation problem are focused either on the surge radiation (Lee and Lee, 1993) or heave radiation (Lee, 1995), where the anchoring systems are either ignored or simplified. In the later studies for an offshore floating structure (Lee et al., 1999; Lee and Wang, 2000a, b) the properties of the anchoring tension-legs were taken into accounts along with the wave-structure interactions, where the large body effects from the pontoon-pier was also under the consideration. The results showed that for the same wave properties, the dynamic behavior of both the tether of the tension leg and the platform itself are closely related to the material property and the tether dimension.

Although these studies accounted for the interaction between the wave and the pontoon-pier structure, the drag effect of tethers on the platform structures was ignored. By ignoring the effect of drag motion of the tethers on the platform, the response of the pontoon-pier could not be estimated accurately. However, after overcoming the complexities of multi-interactions in the previous analysis, the interactions between the pontoon-pier (large body), waves, and tethers (small body) have been taken into accounts in the analytical solutions (Lee and Wang, 2001). It was shown that the inclusion of the tether drag effect drastically reduced the platform amplitude under the same wave conditions.

In this study the interactions between waves and structures are also taken into accounts and moreover, besides the radiation problem induced from surge, the radiation induced from heave and pitch motions of the pontoon-pier is also under consideration. For the side-supporting floating pier system, the motion of the pontoon-pier, basically the surge motion is confined by the pile-columns on two sides of the floating structure. Therefore, the dynamic behavior of the pile-column must be taken into calculation simultaneously along with the response of the pontoon-pier, which in the same time interacts with waves and influence the wave properties that provide exerting pressure on the pile-columns. Based on previous studies (Lee and Wang, 2001, 2003), the equations for the scattering problem and the radiation problem were established at the related boundaries with variables of velocity potential obtained from the Laplace equation. The forcing function related to the velocity potentials was used in the equation of motion for the pontoon-pier and the pile-columns. The analytical solution for the unknown coefficients and the responses of both the pontoon-pier and the pile-columns were found by solving all of the equations derived on the boundaries simultaneously.

The purpose of this study is to investigate the response of a floating pier structural system subjected to incident waves and flow drags on the pile-columns, including the multi-interaction among waves, pontoon-pier structure, and pile-columns. Numerical examples are carried out, and the results are discussed focusing on both the reflection and transmission coefficients and on the motion of the pontoon-pier subjected to waves of various periods. The influence of parameters such as the material property of the pile-columns, dimension of the pontoon and the submerged depth on the pontoon was also studied. It is found that the response of the floating pier structure is significantly dependant on the properties of the pile-columns, the wave conditions and the interactions between the pontoons and the waves.

2. General theory of wave and flow field

2.1. Basic provisions on the problems

Illustrated in Fig. 1 is a two-dimensional schematic view for a typical floating pier structural system, where a set of floatable pontoon are mounted under the deck of the pier while two ends of the deck are connected to a pair of pile-columns fixed to the seabed. The pier-decks are allowed to vertical and rotational motions because the connection joints between the pile-column and the deck are vertically movable hinges. However, even though due to the connection joints the relative horizontal motions between the deck and pile-column are not allowable, the surge motions for the whole floating pier structural system, which includes the pile-columns as well, are allowable and studied.

It is assumed that the water depth, where the floating pier structure is located is h, draught of the pontoon is d and the width of the pontoon is $2b$. In the study, both the large body and small body theorems for the applications of wave force are utilized. For the pile-columns the small body theorem is assumed because the dimension of the pile d_s is usually small compared to the wave length L ($d_s/L<0.2$) while the large body theorem must be applied for the pontoons since the dimension for the pontoon of the floating pier could be larger than 1/5 of the wave-length. Therefore, the interactions between waves and

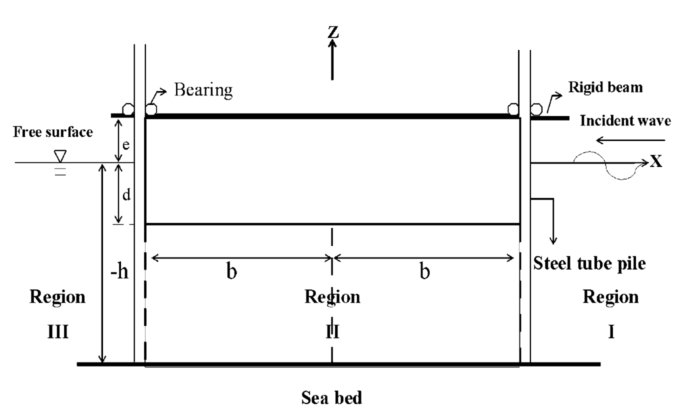

Fig. 1. Sketch of a typical floating pier structural system subjected to waves.