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Lift Force Reduction by Means of a Diffuser for Gravity Base Foundations in Waves and Currents

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An investigation of lift forces acting on gravity base foundations is presented, utilizing the Computational Fluid Dynamics (CFD)-based Virtual Free Surface (VFS) reduced modeling technique. The paper raises awareness of the significant vertical loads that may ensue when currents and waves are subjected to a bluff body. An efficient solution to this design challenge is proposed and analyzed by introducing an under-body diffuser. The structure is tested and analyzed for various pure wave, pure current, and combined wave-current load cases.

INTRODUCTION

In the development of offshore support structures, the horizontal force is often a design determining factor. This is particularly true for piled structures, which are commonly used in the offshore wind sector. For current loads acting on these structures, fluid-induced vertical forces can typically be neglected. However, when fluid motion above a bottom-mounted bluff body develops, considerable vertical forces arise as a result of the flow field. This phenomenon is of particular relevance in the design of gravity base foundations, which rely solely on the gravitational force to counteract this lift force.

For offshore foundation design, research on optimization with regards to lift has not been as extensive compared to other fields such as aeronautics and the automotive industry. Here, the consideration of lift forces in optimal design is an ongoing subject of high interest. Recent publications focusing on this subject include works by Moens and Wervaecke (2013) as well as Marklund (2013). Two distinct concepts are followed in these publications: While the design of an airplane relies on secondary components (wings) to induce lift forces, the automotive sector targets the primary structure by taking advantage of the under-body flow of the car body to influence lift forces. The former approach was adopted for the design process of gravity base offshore structures by Owen and Bryden (2005) and more recently by Harding and Bryden (2012). These works propose the attachment of hydrofoils to tidal turbine support structures to induce a downward force during current loading. When the direction of the tidal flow reverses, the hydrofoils rotate in order to function properly for both current directions. Alternatively, this paper proposes a stationary system that reduces lift forces by adopting the under-body flow concept for the design process of gravity base foundations.

First, a brief introduction of the numerical methods underlying the research of the paper is given. Next, a reference lift force investigation is presented that analyzes the loads on a gravity base foundation without measures to reduce the vertical forces. The structure is improved with regards to lift by introducing a diffuser at the base of the structure. In addition to the steady current considerations typically presented in the literature, this paper also investigates the performance of all analyzed structures with respect to wave and combined wave-current loading.

NUMERICAL METHOD

The Virtual Free Surface (VFS) reduced modeling technique is used to carry out the simulations presented in this paper, as introduced by Markus, Arnold, et al. (2013) and further developed in Markus, Arnold, et al. (2014). An extensive description of the model can be found in these publications while only a brief overview of the method is presented here. The aforementioned papers also include an elaborate model verification study, as well as an application of the method to a force analysis of simple geometries, which interested readers may refer to.

The fundamental approach is to gain access to structural wave and current loads based on the numerical solution of the unsteady Reynolds-averaged Navier-Stokes (URANS) equations. The Reynolds stresses of the equation are modeled by using the k-ω SST model, as introduced by Menter (1993). Traditionally, CFD wave simulations are carried out by coupling the Navier-Stokes solver with a free surface model such as the Volume of Fluid (VOF) method. For ocean engineering application, this approach is thoroughly documented by Yang et al. (2006), Gebreslassie et al. (2012), and Markus, Hojjat, et al. (2013). This approach is feasible when analyzing a few individual structures, but the high computational costs involved in CFD-VOF computations are restrictive in parameter studies or optimization problems. Alternatively, the VFS method allows for computationally cheaper simulations if the application of interest involves a fully submerged structure. In this approach, the computational domain is defined exclusively for the water region, resulting in a more efficient single-phase model. The vertical dimension of the computational domain is limited by what is referred to as the VFS boundary. This boundary is introduced such that the domain is cut below the trough amplitude of the wave. The characteristics of the wave are retained in the model by introducing a time-varying velocity boundary field at the inlet boundary and VFS boundary of the domain in the form of a Dirichlet boundary condition. The wave velocity field is derived by using the Fenton nonlinear wave model according to Fenton (1988).

The boundary condition for the pressure at the inlet and VFS of the domain is defined in the form of a zero-gradient Neumann boundary condition. This specification for the pressure boundary

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KEY WORDS: Lift forces, gravity base, CFD, waves, wave-current interaction, diffuser.