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Time-Domain Simulation of Nonlinear Wave Impact Loads on Fixed Offshore Platform and Decks

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Greenwater damage to offshore structures results from high pressures and dynamic loads that occur when wave crests inundate the structure far above the waterline in areas not designed to withstand such pressures. In this study, a Navier-Stokes numerical method has been employed for the prediction of impact loads of both 3D short-crested and 2D long-crested waves on a fixed platform and its topside equipment. The violent free-surface flow generated by large hurricane waves that reach into the platform deck is resolved by an interface-capturing, level-set method. The Navier-Stokes equations are formulated in a curvilinear coordinate system and discretized using the finite-analytic method. The level-set equations of interface evolution and re-initialization were solved using an implicit 5th-order WENO (weighted essentially non-oscillatory) scheme. An overset grid system is employed to facilitate the simulation of complex flow around a fixed platform with 8 platform legs, an array of 20 risers, and 32 rectangular pegs representing major topside equipment. A new and very efficient grid-interpolation program has been developed to provide the required interpolation data for this complex chimera grid system. Time-domain simulations were performed for both the unidirectional long-crested and directional short-crested waves based on the directional wave spectra of Hurricane Katrina. The simulation results successfully captured the evolution of the wave crest as it propagates through the platform decks while exerting impact loads on the topside equipment in its path. A detailed comparison of the wave impacts and loading difference between the 2D unidirectional waves and 3D directional short-crested wave clearly indicates that the impact loads from short-crested waves differ drastically from those of long-crested waves. Truly big 3D short-crested waves occur in very rare occasions when all wave components of the directional wave spectrum are in phase. However, these extreme storm waves are capable of producing severe local damage to platform decks and topside equipments. The simulation results provide useful guidance for designing new platforms as well as assessing the continued reliability of existing structures.

INTRODUCTION

The impact of hurricane waves on a fixed platform is a complex problem involving wet-deck slamming, greenwater on the platform deck, and wave impact on topside equipment. The new API (American Petroleum Institute) guideline forecasts significantly larger hurricane wave conditions for certain regions of the Gulf of Mexico. While the recent hindcasts and storms used to develop the revised hurricane conditions explain many platform failures, there were some unexpected survivals as well as instances of local damage to topside equipment that was greater than can be explained by hindcast wave conditions. To account for this mechanism, the short crestedness of the storm waves has been proposed as a possible explanation and a correction factor on the hindcast crest height. In order to calibrate or verify the proposed safety factors associated with the global and deck wave force computations per the API guidelines, it is desirable to develop a quantitative assessment tool with which to predict the extent to which wave deck impact loads from short-crested waves differ from those of long-crested waves. The results will affect both the guidelines for designing new platforms and the assessment of the continued reliability and safety of existing structures.

Greenwater loads on offshore platforms occur when storm waves significantly exceed the free board and reach into the platform decks. The primary difficulty in the simulation of the greenwater phenomenon lies in the tracking of the violent air-water interface. Many methods have been proposed to predict the interface between 2 different fluids. They could be classified into 2 general approaches: the interface-tracking methods and the interface-capturing methods. The interface-tracking methods follow the free-surface motions and use boundary-fitted grids adjusted at each time step whenever the free surface moves. In contrast, the interface-capturing methods do not define a sharp free-surface boundary. Rather, the computation is performed on a fixed grid, which is extended beyond the free surface, and the shape of this free surface is determined by cells that are partially filled. Various numerical methods in this interface-capturing approach have been developed over the past several decades; three of the most commonly used interface-capturing methods are the marker-and-cell (MAC) method (Harlow and Welch, 1965); the volume-of-fluid (VOF) method (Hirt and Nichols, 1981); and the level-set method (Osher and Sethian, 1988). In this study, the interface-capturing level-set method is used to provide an accurate simulation of the storm wave impact loads on a fixed offshore platform, its deck and topside equipment. Simulations were performed using both unidirectional long-crested and directional short-crested waves so as to provide quantitative assessment of the effect of a 3D short-crested storm wave on the greenwater patterns and the impact loads on a platform deck and topside equipment.

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