Loads on Tie-down Systems for Floating Drilling Rigs During Hurricane Conditions

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Tie-down systems are used to fasten drilling rigs to the deck of offshore structures to prevent them from moving in harsh environmental conditions such as hurricanes. During hurricanes Ivan (2004) and Katrina (2005), failures in tie-down systems allowed several rigs to move and be damaged. In this study, the reaction force and connection capacity of tie-down systems for a tension leg platform (TLP) and a SPAR are investigated by analyzing the dynamics of the drilling rig and its substructure. For the analysis and simulations in time domain, the hull-mooring-riser coupled dynamic analysis program developed by the authors was used. The 100-year and 1000-year hurricane conditions are taken from the API Bulletin 2INT-MET; which reflects updated conditions following major storms during 2004-05. Based on the simulated motion and acceleration time series, the inertial and gravity loads on derrick and skid base are calculated, in addition to dynamic wind forces for various wind-wave-current (W-W-C) collinear headings. Then the loads that could cause tensile/shear/slip failure at derrick and skid-base footings are computed and analyzed. A new concept called instantaneous slip failure is introduced and demonstrated. Also assessed are the contributions of the centrifugal forces and rotary inertia moments that are often neglected in design practice.

INTRODUCTION

Current offshore structural design is based on the harshest environmental condition expected during service life. However, tie-down systems on several floating drilling and production platforms in the Gulf of Mexico failed during Hurricane Ivan (2004) (Ward et al., 2006), calling attention to the need for more reliable design and assessment methods for tie-down systems (API 1995, 2007, 2008).

In this study, simulations of loads on a tie-down system on 2 types of platforms, a tension leg platform (TLP) and a SPAR, are conducted for hurricane environmental conditions by using a newly developed dynamic analysis tool in the time domain (Yang, 2009). The TLP and SPAR analyzed here were not actual designs, but represented realistic examples of Floating Production Systems (FPS) and a drilling rig. The global motions of the FPS are solved by using the time-domain hull-mooring-riser coupled dynamic analysis tool (Kim et al., 1999) for hurricane wind, wave and current environments that represented 100-year and 1000-year return periods. These motions and loads were used to estimate the maximum forces and moments at the locations where tie-down clamps secure the derrick and drill floor to the substructure, and the skid base to the deck.

There are 3 force components for structures on deck: wind loading; inertia loading due to hull translational and rotational accelerations; and gravity force due to hull inclination. The second and third components depend on hull motion characteristics and can vary a lot from platform to platform (Faltinsen, 1990). The motion characteristics of TLP and SPAR in storm seas are quite different due to the differences in geometric shape and mooring configuration. These differences cause different load magnitudes on tie-down systems. The pitch/roll motions of TLP are much smaller than those of SPAR because of the vertical moorings, called tendons, on each column. Thus, the resulting inertia and gravity loading components of TLP are expected to be smaller than those of SPAR. On the other hand, the deck height (air gap) of a TLP is in general higher than that of a SPAR, which results in larger wind loading. This kind of comparison will be demonstrated in this paper through representative case studies, as an extension of previous studies by the authors (Ward et al., 2007) in which simpler methodologies have been used.

The present derrick dynamic analysis includes centrifugal forces and derrick rotary inertia forces as well as phase differences of wind-inertia-gravity forces, which have usually not been considered by practicing engineers. By using time-domain simulation, including all the phase information among forces, it is shown that the actual external loading on a derrick is 20% to 30% smaller than the direct sum of the maxima of the constituent forces. It is also revealed that instantaneous progressive slip failure may occur even though the total friction force appears to be greater than the total slip force. This interesting phenomenon cannot be detected by any simpler approach currently used by the industry. By varying the heading of winds, waves and currents (W-W-C), it is also found that the maximum uplift and slip forces on the rectangular skid base occur when the incident angle is between end-on and broadside.

HURRICANE ENVIRONMENT

Table 1 summarizes the environmental conditions used in this study; W-W-C representing 100-year and 1000-year hurricane conditions are given. The JONSWAP spectrum with overshooting parameter $\gamma = 2.4$ was used to simulate the corresponding long-crested irregular waves. Time-varying wind speeds were simulated by using the API spectrum. The steady shear currents are given...