International Journal of Offshore and Polar Engineering (ISSN 1053-5381)

Vol. 27, No. 3, September 2017, pp. 283–292; https://doi.org/10.17736/ijope.2017.sh19
http://www.isope.org/publications/publications.htm

Analysis of a Spar Platform with Various Mooring System Configurations Under the Influence of Water Waves

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This paper presents a comprehensive dynamic analysis of a marine spar platform with various mooring system configurations. From a practical viewpoint, the mooring system configuration is managed by reel-motor devices that change cable lengths while keeping all cables under tension. The spar platform is anchored to the seabed by twelve mooring cables (in six cable bundle arrangements), and the domain that the cable-driven spar platform can be within is called the platform effective area. The analysis is based on a global frame of reference at the seabed and a local frame of reference at the platform center of gravity. Under the context of rigid body dynamics, the averaged values of the mooring cable tension are calculated through the use of a second norm measure. The platform dynamic response under unidirectional harmonic water waves and changeable submerged depths is investigated over the entire spar platform effective area. The minimum platform natural frequency at each location within the effective area is used as a measure of the platform degree of rigidity.

INTRODUCTION

Spar floating marine platforms are often used for offshore operations such as oil and gas exploration and production and wind energy harvesting. A spar platform consists of a floating structure that is connected to a heavyweight spar and anchored to the seabed by a cable-based mooring system. The first spar platform in the oil industry was installed in the North Sea in the 1970s and used for oil storage and offloading (Bax and de Werk, 1974; Van Santen and de Werk, 1976). While the floating platform is exposed to the environmental loads, the mooring system has the objective of retaining the floating structures' location. Commonly used mooring systems consist of three cables (Karimirad and Moan, 2012; Jeon et al., 2013; Muliawan, Karimirad and Moan, 2013; Muliawan et al., 2013; Si et al., 2014; Kim et al., 2014; Yu et al., 2015), four cables (Downie et al., 2000; Chen et al., 2001; Sethuraman and Venugopal, 2013), nine cables (Zhang et al., 2007; Zhang et al., 2008; Montasir and Kurian, 2011; Montasir et al., 2015), and twelve cables (Wang et al., 2008; Yang et al., 2012).

A number of researchers analyzed the dynamic response of spar platforms through the use of different numerical and experimental techniques. The spar platform motion was investigated by Ran et al. (1996) through the use of a higher-order boundary element method, and they compared their numerical results with the measurement data, showing good agreement. Jha et al. (1997) obtained an analytical prediction for wave drift damping and viscous forces that influence the dynamic response of spar platforms. The effect of nonlinear sea waves on the dynamic response of a spar platform was investigated by Anam and Roesset (2002) through the use of the hybrid wave, stretching, and extrapolation models. Using Morison's equation, Anam et al. (2003) studied the differences between the time domain analysis and frequency domain analysis in predicting the spar platform slow drift response. Agarwal and Jain (2003) studied the spar platform's nonlinear coupled dynamic response when the spar platform was exposed to regular sea waves, and they modeled the mooring lines as nonlinear horizontal and vertical springs. Nonlinear heave-pitch interaction was found to cause instability in the dynamic response and led Lim et al. (2005) to study the motion characteristics of a cell spar platform. An experimental setup for a hybrid model testing technique was utilized by Su et al. (2007) to study the motion of a cell-truss spar platform. Time-domain and frequency-domain analyses of a cell-truss spar platform with various degrees of coupling were conducted by Zhang et al. (2007, 2008). Leira et al. (2008) studied the dynamic response of a spar platform under the effect of the sea waves and wind forces. The structural design and hydrodynamic analysis of an s-spar were considered by Yu and Huang (2010). The effect of environmental forces with different frequencies on the dynamic response of a truss spar platform was studied by Montasir and Kurian (2011). Jameel et al. (2013) focused on the importance of the coupling effects on the motion of a spar platform and studied the effect of damping on mooring lines. Montasir et al. (2015) investigated the effect of symmetric as well as asymmetric mooring system configurations on the motion response of a truss spar platform.

Other researchers concentrated on the stabilization of spar platforms; namely, they worked towards the minimization of the dynamic response using heave plates (Magee et al., 2000; Zhang et al., 2006). Experimental results and numerical prediction showed that heave plates helped to reduce the heave response of spar platforms. In addition, the heave damping augmentation effect on the heave behavior of a classic spar platform was studied experimentally by Fischer and Gopalkrishnan (1998). Their results showed that each additional damping plate increased the total damping of the classic spar platform. Solid and perforated heave plates were used by Downie et al. (2000) to study experimentally their effect on the dynamic response of a truss spar platform. It was found that the heave response was smaller for the spar platform with larger and solid plates than for that with smaller and perforated plates. An alternative solution for stabilizing spar platforms was derived by increasing viscous damping due to changing the hull geometry (Haslum and Faltinsen, 1999; Tao et al., 2004).

Spar platforms studied in the literature have mooring systems made out of cables with fixed lengths and one mooring configuration (e.g., Ran, 2000; Koo et al., 2004; Zhang et al., 2007; Wang

Received November 22, 2016; revised manuscript received by the editors February 14, 2017. The original version was submitted directly to the Journal.
KEY WORDS: Spar platform, mooring system, dynamic analysis, effective area.