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Response of nonlinear offshore spar platform under wave and current

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ABSTRACT

Several advanced floating structures have been proposed and developed with varying cost effectiveness and productiveness in deep water exploration. Among them, Spar platforms have been accepted as an efficient platform for the exploration. Many research works have been conducted on floating structure but a few on Spar platform. Nonlinear dynamic analysis of a 3D model of floating Spar platform structure is a resourceful tool to predict the responses, where the main body of the Spar hull and mooring lines are considered as an integrated coupled system. To define accurately the interaction between the Spar and mooring lines, coupled dynamic analysis was found to be appropriate for studying responses in the deep sea. Numerical simulation and motion analyses were carried out with the ABAQUS/AQUA. The responses of Spar platform were extracted and evaluated in time histories along with Response Amplitude Operator (RAO). The behaviours of coupled Spar platform have been investigated under real sea environments for increasing water depth to ultra-deep together with the load variability employing sea current for surge, heave, pitch and mooring tension responses. Motions show the consistency in the behaviour of Spar platform responses. Surge response indicates the static offset of the platform due to the static current force under wave plus current. The current force compresses oscillations and reduce heave and pitch magnitude. For larger water depth the platform responses reduce significantly due to the increased damping of mooring line.

1. Introduction

Growing demand for hydrocarbons, Oil and gas exploration in deeper water has become great challenge and concern in all over the world. Expansion of the petroleum industry in the world into the deep seas and the oceans has become inevitable. Ordinary fixed type of jacket offshore structure is not economical for deep water condition. It has also been proven that employing these for deep water condition is not suitable. Several developments and approaches have been recently employed for deep water investigation of oil and gas like the tension leg platform, the tethered buoy tower, the articulated leg platform, etc. Among all the platforms, Spar floating platform has been found suitable for drilling and production of oil and gas from deep and deeper sea (Glanville et al., 1991; Horton and Halkyard, 1992). Structurally, it is a rigid cylinder with 6 degrees of freedom, anchored to the sea-bottom by vertical or catenary cables (Ma and Webster, 1994) (Fig. 1). Various works on spar platforms have been covered in the literature (Glanville et al., 1997; Halkyard, 1996). However, consideration of significant nonlinearities is very important for structural idealization (Islam et al., 2011a, b). This platform is the best suited and cost-effective for drilling, production and offloading of ocean hydrocarbon in deep water exploration. It consists of a cylindrical body which floats in the water. The action of the wave on the surface is reduced by the opposite effect of the net structural buoyancy at deep water. There is a fin like structure which is called strakes. It is attached in a helical fashion around the outside of the cylinder. It acts to break the water flow against the structure and thus, enhances the stability of the structure. Different types of catenary mooring lines (Sarkar and Eatock Taylor, 2002) are attached to the hull near its centre of pitch. The effect of mooring lines on spar platforms (Montasir et al., 2015) becomes more significant with the increasing water depth. The coupled action of the spar mooring system changes the behaviour of the spar hull. A number of studies have been conducted to assess the effect of coupling on different offshore spar floaters. Spar platform, which proved to be an economical floating structure was used for deep water oil and gas exploration (Islam et al., 2012). There are some advantages of using floating platforms. It can move from one place to another place at ease

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Nomenclature

[C]	Damping matrix
d	Water depth
fs	Frequency increment
g	Gravitational acceleration
H	Wave height
k	Wave number
[K]	Stiffness matrix
[M]	Mass matrix
N	Number of data points in each section
T	Wave period
t	Time
Ts	Total data length
u	Horizontal velocity
$\dot{u}$	Horizontal acceleration
w	Vertical velocity
$\dot{w}$	Vertical acceleration
Δt	Time increment
ω_i	Natural frequency
ξ	Structural damping ratio
{X}	6 DOF structural displacements at each node
$\{\dot{X}\}$	Structural velocity vector
$\{\ddot{X}\}$	Structural acceleration vector

Fig. 1. Spar platform (MarineInsight, 2016).

and also can repeatedly be used, which is useful for the marginal reservoirs. Also, Production time can be reduced after the discovery of the reservoirs. Finally, designs of the floating structures may not be affected by the water depth and earthquakes.

In a coupled dynamic analysis, the boundary conditions between the mooring system and the floating structure need to be properly modelled. Efficient code is vital for a coupled dynamic analysis. COUPLE and SMACOS dynamic analysis program was developed by (Chen et al., 1999). Where, COUPLE is a coupled dynamic code and SMACOS is a quasi-static analysis code. Many researchers (Chen et al., 2001; Colby et al., 2000; Gupta et al., 2000; Jha et al., 1997) have evaluated effect of coupling on the spar platforms. Ma and Patel (2001) have discussed nonlinear forces on the spar platform in deep water. Several Investigations have carried out on coupled dynamic analysis of hull, mooring and riser of spar floating platform (Anam, 2000; Chen et al., 2006; Garrett, 2005; Islam et al., 2011a; Kim et al., 2005). Tahar and Kim (2008) have used polyester mooring lines to establish a numerical approach for deep water coupled spar platform. Some other researches with Numerical simulation and model experiments have been done on nonlinear coupled response analysis of spar and other floating structures (Islam et al., 2013, 2011a; Liu et al., 2013; Yang and Kim, 2010; Zhu and Yoo, 2015). Also, nonlinear and dynamic response analyses of the

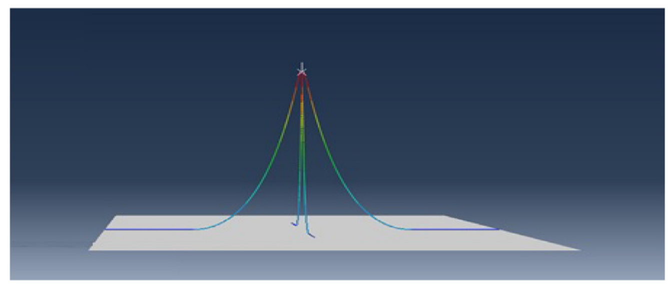

Fig. 2. FEM model of spar hull and mooring lines.

floating offshore spar platform have been carried out for ultra-deep water region (Islam et al., 2016).

Therefore, the objective of this paper is to develop a model and employ a precise coupled dynamics for ultra-deep water spar platform for oil and gas exploration along with its behaviour and responses in the ocean environment. To evaluate the effect of wave and current force on the moored Spar platform along with Response Amplitude Operator (RAO) of the Platform.

2. Spar platform model

In this study a floating spar platform was selected which consists of three major parts, i.e. spar hull, mooring line and seabed. The spar hull was modelled as rigid beam which was anchored at fair lead position and seabed by mooring lines. The spar platform was connected to the elastic mooring lines using six springs (Three for translational motion as surge, sway, heave and three for rotational motion as roll, pitch and yaw). The individual stiffness of the translation spring was very high, whereas those of the rotational springs were very low of simulating a hinge connection. Catenary mooring lines induces nonlinearities because of fluctuating pretension and low strain deformation. Besides, mooring lines do not penetrate on the seabed and contact between them is frictionless and surface to surface. In the present study, the surface of seabed and the circumferential surface of mooring line were selected for contact interaction. Finite element code ABAQUS was used to develop integrated coupled Spar platform and mooring line model (Fig. 2). Finite element method can analyse of a Spar platform including the coupling action between the Spar and the mooring lines. When the Spar platform is in actual environmental condition, hydrodynamic loads from the wave and the current act concurrently to the Spar-mooring system. But during the analysis and simulation process with finite element method, it acts as a continuum. ABAQUS is a suitable and appropriate software for the analysis of this study. Also, AQUA has been used in the study. It is capable of analysing and simulating hydrodynamic loads due to the wave and current. For nonlinear coupled dynamic analysis, the geometric