Effect of Mooring Line Damage on the Responses of Truss Spar Platforms

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***Abstract*-The exploration of hydrocarbon reservoirs in ultra deep water requires the use of innovative floating platform configurations. Due to the global climate change, unexpected ocean environments lead to damages on many offshore platforms. This paper addresses the effect of mooring line damages due to the dynamic responses of truss spar platforms in regular waves. The motion responses have been determined using a time-domain simulation. Quasi static analysis of mooring lines has been conducted to obtain the mooring lines stiffness. Wave forces are calculated using Morison's equation. The numerical results show that missing of mooring lines affect surge motion more than heave and pitch motions.**

I. INTRODUCTION

The spar platforms for offshore oil exploration and production in deep and ultra deep waters are increasingly becoming popular. A number of concepts have evolved, among them the 'classic' spar and 'truss' spar being the most prevalent. The classic spar has an upper buoyant cylindrical hard tank, a keel ballast tank (soft tank) and a flooded cylindrical midsection. The long middle section has large diameter and its design is mostly governed by construction loads. The truss spar platform is very cost-effective. In the late 1990s, development of truss spar concept advanced much with a large amount of research effort using model tests [1], and theoretical study [2]. Since then, ten types of truss spars have been designed, constructed and/or installed.

The truss spar consists of a top hard tank and a bottom soft tank separated by a truss midsection. The soft tank mainly contains solid ballast to provide stability, whereas the hard tank provides buoyancy and contains trim ballast. The truss section contains a number of horizontal heave plates designed to reduce heave motion by increasing both added mass and hydrodynamic damping.

Several analytical or numerical approaches can be used to calculate the dynamic response of spars. The most direct approach is the analysis in the time domain, where a wave elevation time series is used as input and the resulting structural responses are calculated numerically. In the structural analysis, it is common practice to treat the mooring lines and risers as springs. This neglects the inertia of the mooring system, as well as the additional drag forces that may increase the damping of the total structure.

Simulation of the motion of a spar buoy requires the definition of the equations of motion and the evaluation of all forces acting on it due to wind, current ocean waves and mooring lines. The conventional approach in offshore engineering is to use the linear form of the equations to describe the motions of rigid bodies. For large motions the non-linear equations of motion [3] should be used but it is only practical if the exciting forces can be calculated without evolving wave diffraction analysis.

A key element of the analysis of a spar buoy is to evaluate the applied forces and moments on it due to ocean waves and currents. One of the possibility to obtain these is to perform a numerical analysis of the fully non-linear interaction between the spar and its surrounding fluid. Although it is not impossible, this task require very powerful computer resources and is, therefore, not feasible in practice. An alternative approach is to carry out a diffraction analysis based on second order potential theory (see for example, Ran et al. [4]). The computation cost of this approach is still quite high. Also this method usually generates results in the frequency domain and thereafter a transformation is needed to obtain forces in the time domain.

Another approach, often used in offshore engineering for wave force evaluation, is based on slender body theory that requires much less computational effort and can be directly implemented in time domain analysis. In this approach, the body is assumed 'thin' and the force (and/or moment) is obtained by the sum of the force on each short segment of the slender body. The force in each segment is decomposed into two parts - an in viscid force and viscous drag force. One typical slender body wave force formulation is the well-known Morison equation, in which the first part is proportional to the relative acceleration and the second part to the product of the relative velocity.

This study is a part of a PhD research which is focus on the dynamic responses of truss spar platform. The main objective of this paper is to investigate the importance effect of missing one or more of the mooring lines on the truss spar motions.

II. NUMERICAL PROCEDURE

In consideration of the incident waves that are long crested and advancing in the x-direction, a spar is approximated by a rigid body of three degree of freedom (surge, heave and pitch), it derives its static resistance from support systems (mooring lines, risers) and hydrostatic stiffness.

Two coordinate systems are employed in the analysis (see fig.1), the space fixed coordinate system oxz and two dimensional local coordinate Gζη which is fixed on the body with the origin at its center of gravity (CG). B is the center of buoyancy and F denotes fairlead.

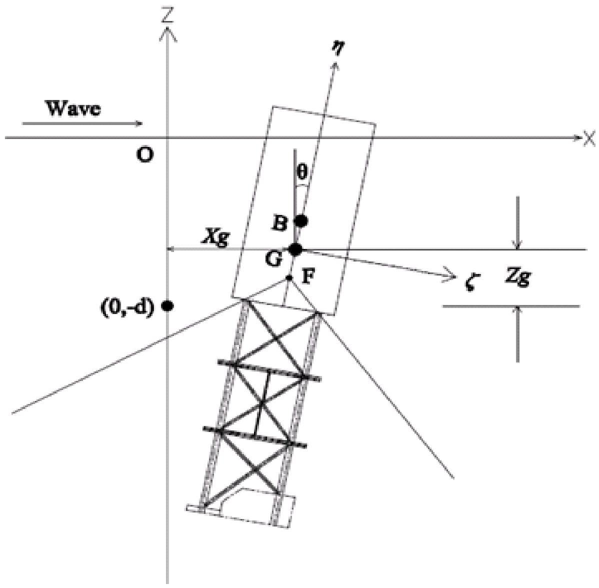


Figure.1. Three DOF Surge-heave-pitch Model of the Spar

The dynamic equations of the surge-heave-pitch motions of the spar are:

$$[M]\{\ddot{X}\}+[C]\{\dot{X}\}+[K]\{X\}=\{F(t)\} \quad (1)$$

where:

- $\{X\}$ is the structural displacement vector with respect to the center of gravity,
- $\{\dot{X}\}$ is the structural velocity vector with respect to the center of gravity,
- $\{\ddot{X}\}$ is the structural acceleration vector with respect to the center of gravity,
- [M] is a mass matrix = $M^{SPAR} + M^{Added\ Mass}$
- [K] is stiffness matrix = $K^{Hydrostatic(hy)} + K^{Horizental\ Spring(hz)}$,
- [C] is structural damping matrix.
- [F(t)] is the hydrodynamic force vector and is calculated using modified Morison equation.

The wave forces are decomposed into the normal force F_{EXn} and tangential force F_{EXt}

$$\begin{bmatrix} F_{EXn} \\ M_{EX} \end{bmatrix} = \int_{-d_1}^{\varsigma} \rho(1+C_m)A(n)a_n \begin{Bmatrix}1\\n\end{Bmatrix} dn$$

$$+ \int_{-d_1}^{\varsigma} \frac{1}{2}\rho C_D D\left|V_n\right|V_n \begin{Bmatrix}1\\n\end{Bmatrix} dn \quad (2)$$

where

$$a_n = \left|a - \left(a.\vec{\tau}\right)\vec{\tau}\right|$$

$$V_n = \left|V - r_s - ((V - r_s).\tau)\tau\right|$$

$$F_{EXt} = \iint \rho \frac{\partial \vartheta_1}{\partial t} + \frac{1}{2}\rho\left|\nabla \vartheta_1\right|^2 n_t \partial s \quad (3)$$

Cm is the added mass coefficient, Cd is the drag coefficient, V_n the relative normal velocity and $\vec{\tau}$ is a unit vector along the n-axis. a and V are respectively wave particle acceleration and velocity and r_s is strucure velocity.The tangential force can be determined by integrating the hydrodynamic pressure on the bottom surface. ϑ_1 is the first order potential of incident waves.

In time domain using numerical integration technique the equation of motion can be solved, incorporating all the time dependent nonlinearities, stiffness coefficient changes due to mooring line tension with time, added mass from Morison equation, and with evaluation of wave forces at the instantaneous displaced position of the structure. At each step, the force vector is updated to take into account the change in the mooring line tension. The equation of motion is solved by an iterative procedure using unconditionally stable Newmark Beta method and this is programmed using MATLAB.

III. RESULTS AND DISCUSSION

Any floating offshore structures connected to the sea bed using mooring lines should have some redundancy. However, damage of mooring lines will affect the dynamic responses of the system.

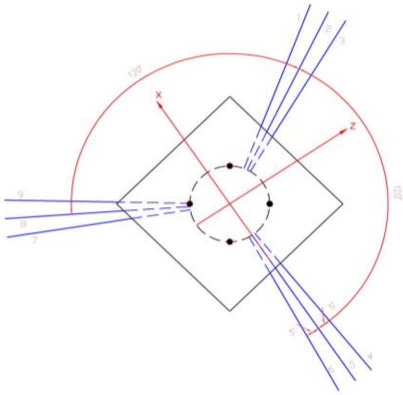
A numerical simulation for Marlin truss spar with nine mooring lines as shown in Fig. 2 (three in each group), was conducted. The physical characteristics of the structure and the characteristics of the mooring lines are summarized in tables I and II respectively.

Each mooring line consisted of a chain-wire-chain taut leg having the same geometric and material properties of the prototype mooring system. The mooring lines were assumed to be hinged at both ends. Each mooring line was given an initial tension equal to 2312 KN.

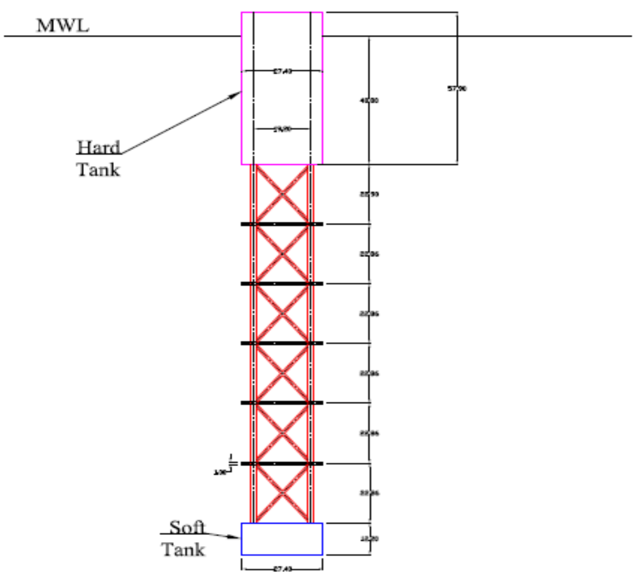
TABLE I

PHYSICAL CHARACTERISTICS OF MARLIN TRUSS SPAR

Weight	389,80 ton
Vertical centre of gravity (KG)	126.34 m
Buoyancy, basic	389,80 ton
Vertical centre of buoyancy (KB), basic	152.4 m
radius of gyration for pitch	86.2 m



a) Mooring lines arrangement



b) Overall spar configuration

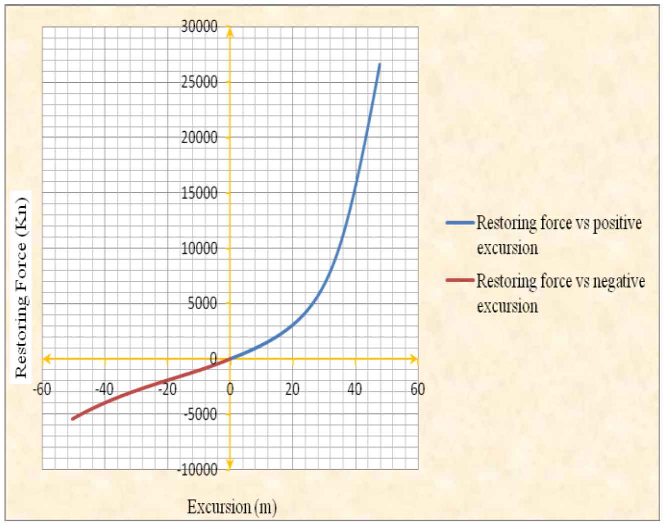
Figure 2. Marlin truss spar

TABLE II

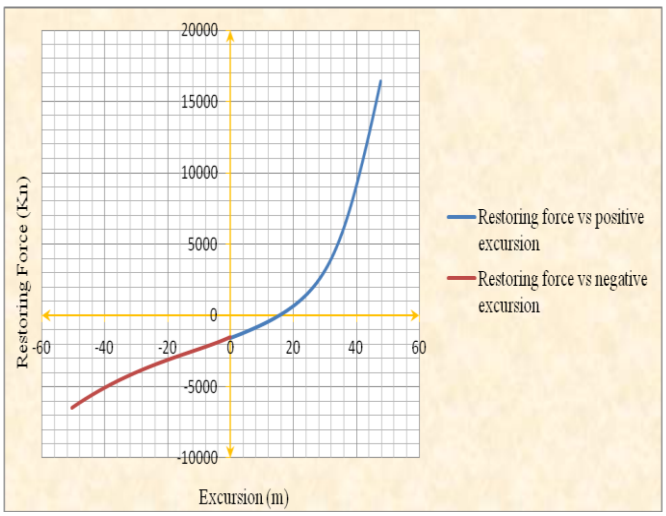
CHARACTERISTICS OF MOORING LINES

	Upper section	Middle section	Lower section
Type	K4 chain	K4 chain	K4 chain
Size (m)	0.124	0.124	0.124
Length (m)	76.2	1828.8	45.72
Wet weight (kg/m)	280.5	65.4	280.5
Eff. modulus EA (Kn)	665,885	133,8915	858,925
Breaking strength (Kn)	131,89	124,55	131,89

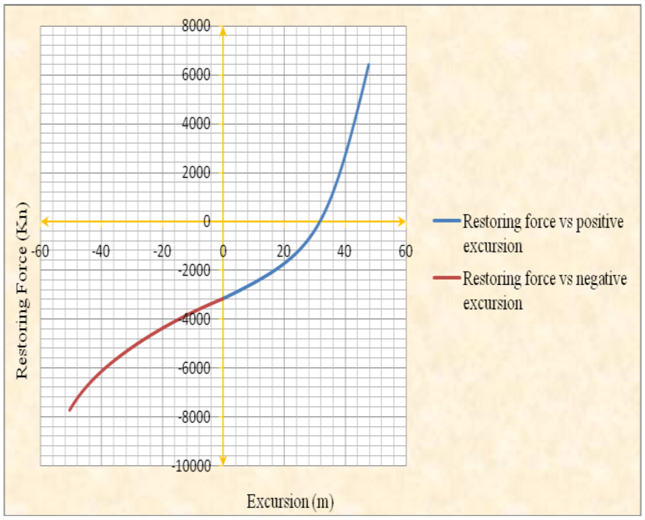
The static offset tests were numerically conducted by applying variable static forces at the fairlead position. As a result, mooring line stiffness curves were obtained. Figures 3 show the effect of missing one and two mooring lines on the mooring lines restoring force. It was shown that missing of mooring lines gives restoring force to the system at zero horizontal offset due to the unbalance between the resultant mooring lines tensions at each side. This restoring force increased when more mooring lines were missed. One more effect of missing mooring lines was decreasing the magnitude of the restoring force.



a) Surge static offset test: offset vs. restoring force.



b) Surge static offset test (missing line5): offset vs. restoring force.



c) Surge static offset test (missing line5 and 6): offset vs. restoring force.

Figure 3. Static offset simulation

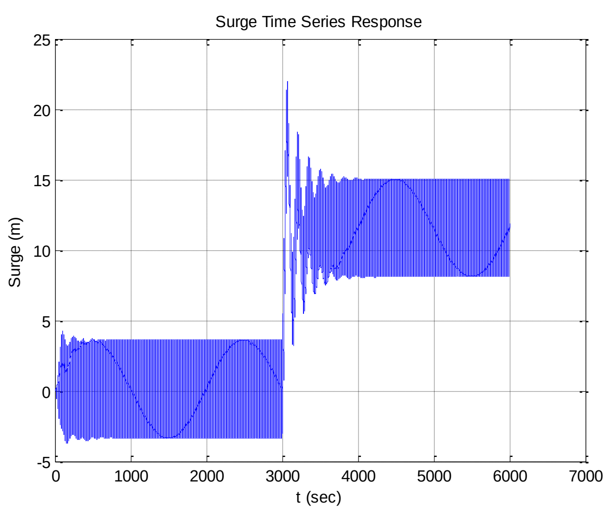
Time domain analysis for the particular truss spar was conducted to obtain the dynamic responses. This was done for three cases:

Case1: complete set of mooring lines

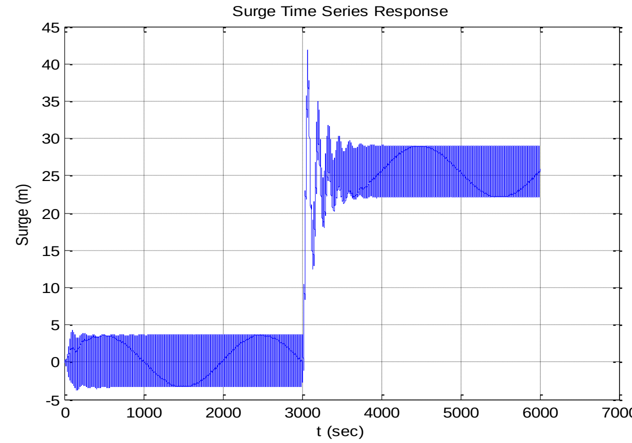
Case2: Missing of line 5

Case3: Missing of lines 5 and 6

Regular wave with H=13m and T=16sec was used in the simulation. The comparisons between the results in the three cases are shown in figures 4, 5 and 6. Up to 3000 sec. the structure was under case1 after that one/two mooring lines was assumed to be damaged. For surge and pitch motions, the mean position of the structure is transfer to another location when one/two mooring lines are damaged. Heave motion slightly affect by damage of mooring lines. For all the three cases, surge, heave and pitch amplitudes were remain almost same.

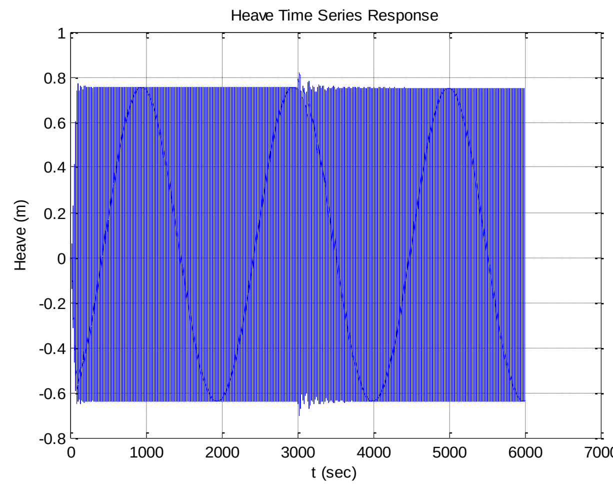


a) Surge time series –case2.

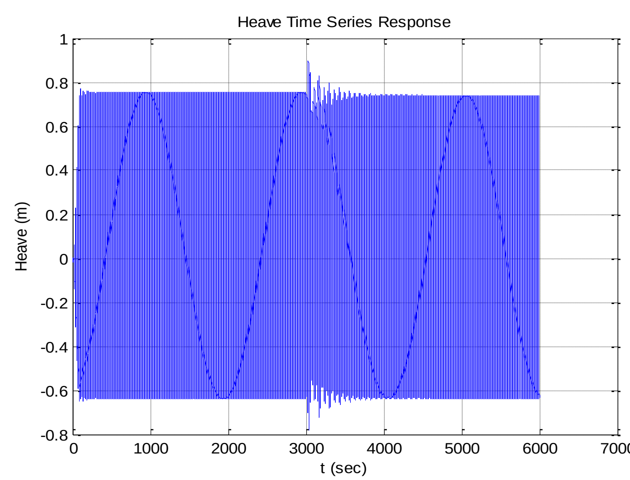


b) Surge time series –case3.

Figure 4. Surge motion

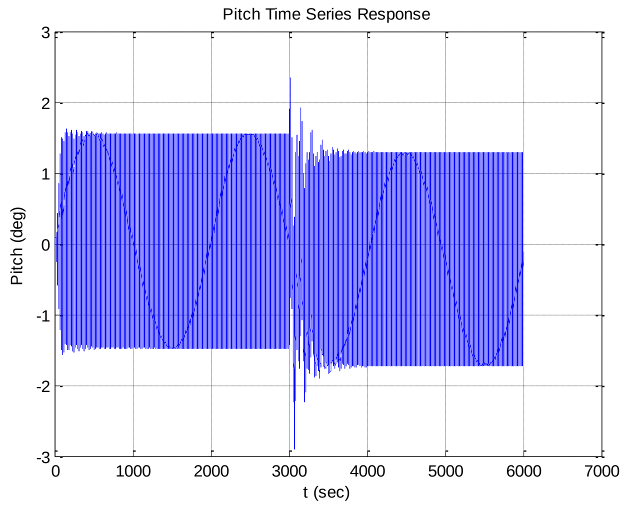


a) Heave time series –case2.

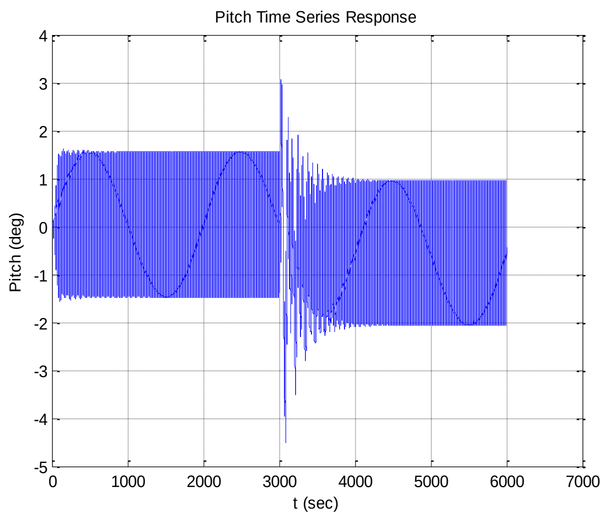


b) Heave time series –case3.

Figure 5. Heave motion



a) Pitch time series –case2.



b) Pitch time series –case3.

Figure 6. Pitch motion

V CONCLUSION

Based on results and discussions, following main conclusions were drawn from this study:

1. The effect of damage of mooring lines on the dynamic responses of a truss spar platform subjected to regular wave was investigated by numerical time domain analysis.
2. The surge responses were greatly affected, they resulted in an offset of 12 m for one missing line and 25 m for two missing lines.
3. The heave and pitch responses were not much affected.

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