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Modeling and Analysis of in Line and Cross Flow Vibration of Risers in Drill Ships

A. Moghiseh[1], A. Rahi[2]*, H. Riahi[3]

1- M.Sc. Student, Department of Mechanical Engineering, Razi University
2- Assistant Professor, Department of Mechanical& Energy Engineering, Shahid Beheshti University
3- M.Sc. Student, Department of Mechanical Engineering, Razi University

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ABSTRACT

In the last few years, drilling activities took place in water depths of more than 3000m. In order to convey the hydrocarbon to the sea level and do drilling operations, a steal pipe is installed between the wellhead in the seabed and drill ships. A control system keeps the drill ship in a safe area above the wellhead. Since the diameter of the riser is much less than its length, it can be simplified into the beam model. The fluid dynamic forces are expressed in Morison formula by using short wave theory. It is assumed that the riser is connected to the drill ship by means of a heave compensator. This device provides a large static tensile force at the top of the riser. In addition, it reduces the longitudinal stress variation induced by the relative vertical motion of the drill ship and the riser. With these assumptions, the equations of motion governing the transverse displacement of the riser in two directions are obtained. These equations are solved by using the finite difference method and Runga-Kutta method. At the end, the effects of environmental and mechanical parameters on the dynamic behavior of the riser are discussed.

KEYWORDS:

Riser, Drill Ship, Compensator, Natural Frequency.

* Corresponding Author, Email: abbasrahi@pwut.ac.ir

1- INTRODUCTION

In the last few years, drilling activities took place in water depths of more than 3000m. In order to convey the hydrocarbon to the sea level and do drilling operations, a riser is installed between the wellhead and drill ships. A control system keeps the drill ship in a safe area above the wellhead. The fluid dynamic forces are expressed in Morison formula by using short wave theory. It is assumed that the riser is connected to the drill ship by means of a heave compensator. This device provides a large static tensile force at the top of the riser. In addition, it reduces the longitudinal stress variation induced by the relative vertical motion of the drill ship and the riser. With these assumptions, the equations of motion governing the transverse displacement of the riser in two directions are obtained. These equations are solved by using the finite difference method and the Runga-Kutta method. Yan-Qiu and Lou [1], [2] investigated the vibration of a simple support beam including nonlinear equations. Also Chi [3] and Tang [4] considered the dynamic response of a riser due to vortex flow and lift force. Several numerical analyses using finite element and finite difference methods to predict dynamic lifting are carried out. Suzuki [5] studied the behavior of flexible risers with on top excitation. Chatjigeorgiou [6] found a closed form mathematical solution for two first natural modes of an excited riser. Kuiper [7] considered a dynamic model of a riser in a floating platform with lateral and vertical motion and hinge pined end. In this paper the effect of wave, fluid flow, motion of drillship and internal fluid are considered.

The aim of this study is to predict dynamic behavior of the riser in synchronic occurrence of wave, current, platform excitation and tension. In addition, the natural vibration frequencies are obtained, and the response including resonance under combined wave-current are investigated.

2- FORMULATION

With the above assumption the dynamic equations are obtained in two directions of in line flow and cross flow. These equations are solved by using numerical methods for a marine riser. To estimate hydrodynamic forces due to wave and current Morison's formula is used. The dynamic equilibrium of the drillship riser in two directions is formulated as (1), (2). To drag and lift force calculation, it is assumed that the current and wave act are in the same direction.

$$EI\frac{\partial^4 w}{\partial z^4} - \frac{\partial}{\partial z}\left[T_{e(z,t)}\cdot\frac{\partial w}{\partial z}\right] + m_t\cdot\frac{\partial^2 w}{\partial t^2} = F_{IL(z,t)} \tag{1}$$

$$EI\frac{\partial^4 y}{\partial z^4} - \frac{\partial}{\partial z}\left[T_{e(z,t)}\cdot\frac{\partial y}{\partial z}\right] + m_t\cdot\frac{\partial^2 y}{\partial t^2} = F_{CF(z,t)} \tag{2}$$

where EI is bending stiffness, $T_{e(z,t)}$ is axial tension, m_t is total mass per length, $F_{IL(z,t)}$ is in-line force, $F_{CF(z,t)}$ is cross flow force, w is in-line displacement and cross flow force. It is explained that the riser does not have constant tension along its length. It is important to note that the natural frequencies are dependent on the platform position and change with time. To obtain natural frequencies, the free vibration equation is solved by using power series methods.

$$w = \sum_{n=0}^{\infty} a_{n+1(c)}.z^{n+c} \tag{3}$$

In other words, the system is changing during time. Figure (1) presents the used model in this formulation. Natural frequency is calculated by using the variable axial tension method [8]. The boundary conditions at the ends of the riser are given as:

$$At\ Bottom\ End\begin{cases} w_{(l,t)} = 0 \\ EI\dfrac{\partial^2 w}{\partial z^2}_{(l,t)} = 0 \end{cases} \tag{4}$$

$$At\ Upper\ End\begin{cases} w_{(0,t)} = 0 \\ EI\dfrac{\partial^2 w}{\partial z^2}_{(0,t)} = 0 \end{cases} \tag{5}$$

To study the dynamic equilibrium the original nonlinear equations of motion are solved using finite difference and Range-Kutta numerical methods. The following initial conditions are used:

$$\left.\left(\frac{\partial w}{\partial t}\right)\right|_{z,t=0} = 0 \tag{6}$$

$$w\big|_{z,t=0} = 0 \tag{7}$$

3- RESULTS

Figure (2) illustrates the riser dynamic equilibrium in three positions of drillship. In t=440 s, the drillship is in the lowest position and displacement near the seabed is increased due to drop axial tension. In t=450 s drillship is moving up on a wave and axial tension increase. In t=460 s the drillship is on the highest position and maximum axial tension acts to the riser. At this time, the riser has its minimum displacement due to the increase of axial tension. It can be seen that reduction in axial tension along the riser is due to platform movement or submerged weight caused by the vibrating pulses which were created and transverse near the seabed. These pulses can move along the riser until they disappear due to water damping effects. The stiffness of compensator has a significant influence on riser dynamic behavior. A soft compensator decreases the effect of drillship position. In addition, the influence of compensator factor is significant. In the present research first three natural frequencies of risers in different drillship positions are obtained. The frequency variation is because of the axial tension changes depending on the drillship position on waves.

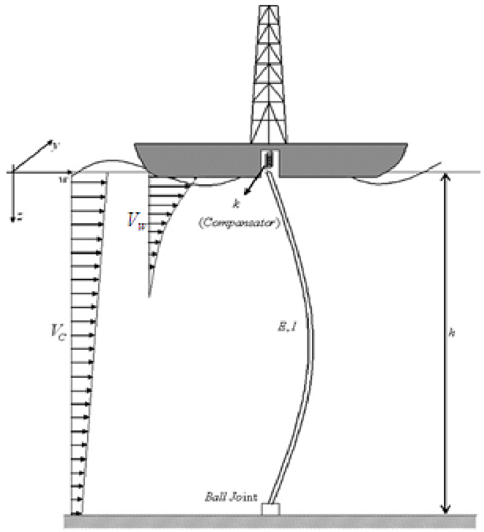

Figure (1): drillship and riser model

Figure (3) presents the displacement distribution along the riser in the first three resonance modes for In-Line vibration. Transverse vibration increases significantly in resonance modes. In addition, deflection pulses move faster along the riser and can encourage each other. Due to the water damping effect, the amplitude of pulses decreases along the riser. In resonance modes, these pulses can reach each other.

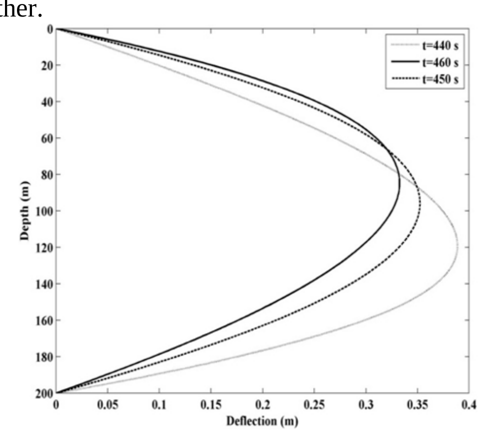

Figure (2): Riser dynamic equilibrium

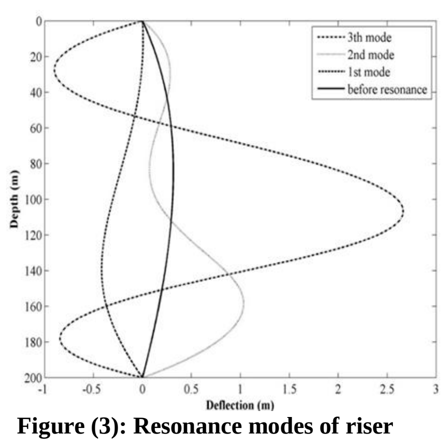

Figure (3): Resonance modes of riser

4- CONCLUSION

In this paper a mathematical model of IL and CF vibration is suggested for the riser in deep waters and the dynamic responses of the riser are obtained in two plans. The effect of variation in mathematical and environmental parameters on the dynamic behavior is considered. In addition, the resonance modes of the riser are studied. By processing the results data, the following conclusions can be drawn:

1. Around the sea level, the wave field dominates dynamic behavior and creates deflection pulses. These pulses do not have enough energy to travel along the riser and vanish before they reach each other.
2. Reduction in axial tension along the riser due to platform movement or submerged weight caused the vibrating pulses to be created and transverse near the seabed. These pulses can move along the riser until they disappear due to water damping effects.
3. If vibrating pulses are created and move with a sufficient speed, they can enrich each other and amplify displacement. This phenomenon appears when the resonance modes occur.
4. If the mechanical parameters, k and f, are inexactly determined, the effects of drillship motion on the dynamic behavior of the riser increases intensively and can cause large deflection especially around the wellhead.

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