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Influence of Joint Stiffness on the Free Vibrations of a Marine Riser Conveying Fluid

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ABSTRACT

The marine risers are generally used as the main transport means for economic materials and resources discovered undersea. In general, the marine risers are secured at either an offshore platform or a vessel. Both ends of the riser are to be adjusted to obey with the design criteria but in many cases their rotational stiffness is hardly set free for the hinge connection. This paper integrates the analytical investigation and the design consideration for the effects of end supports on the free vibrations of a marine riser conveying fluid. It is well known that resonances of marine risers/pipes can cause excessive stress and strain responses, leading to ultimate fatigue failure of the riser system. To avoid a resonance resulting in the sustainable use of the riser, the study to evaluate the influence of end rotational stiffness on the natural frequency of a marine riser conveying fluid is imperative. Using variational principle, the riser model formulation includes both the bending rigidity and the axial elasticity. Using Galerkin finite element method, the natural frequencies and their corresponding mode shapes are determined. The highlight in this paper is the free vibration behaviours in the transition from hinge to fully fixed ends, which can indicate a health monitoring methodology of the risers. The design concepts for the marine risers/pipes conveying fluid to minimize the influence of support conditions are discussed herein as a guideline for structural offshore engineers.

KEY WORDS: Marine risers; pipes; Free vibrations; Natural frequency; Rotational joint stiffness; internal fluid; Galerkin finite element method.

INTRODUCTION

Offshore structures are built mostly to suit the energy and mining industry. The natural resources discovered under sea bed are transported to the sea surface in order to store and process the raw materials. Marine risers/pipes are such main component connected to the floating offshore platforms. There are a number of different types of platforms such as jacking platform, tensioned leg platform, or even ship vessels. Those platforms will be the temporary storage of the hydrocarbon resources drilled from the sub sea, before shipping to the refinery or other manufacturing processes. In construction, the typical connection between the vessel and the top end of the risers is arranged as close as a hinge support, which is adopted for the riser analysis and design. However, in certain circumstances, the connection is restrained by fastening system and/or shock absorber. This has led to the semi-rigid connection behaviour at the top end, which would be different from the earlier analysis and design of the risers. This constraint can also be caused by the welded connection and the improper design of bolt patterns. Although these semi-rigid joints have been often observed in a number of offshore civil constructions (Lennon, 2008), it is found that the investigations related to the dynamic behaviours are inadequate.

Typically, the marine riser consists of steel pipes attached to the floating support by a constant top tension. It is usually kept almost straight or nearly vertical as shown in Fig. 1. In two dimensional space, it is commonly modeled as a beam-column-like structure with internal fluid flowing inside. In practice, the riser is installed along the vertical position. After the riser subjected to its own weight, internal and external pressures, and current and wave forces, it deforms to an equilibrium position (Kaewunruen et al., 2005). After the static deformation, the vibration of the riser can occur due to surrounding excitations afterwards, e.g. vortex shedding, hydrodynamic force, etc. It is imperative to investigate the vibrational behaviour of the marine risers in order to avoid excessive displacements due to a resonance (Leklong et al., 2008). These large displacements yield excessive stresses along the riser, resulting in the decrement of service life of the risers. This would not allow the riser to be reused in other projects or applications. The sustainability in design and construction cannot thus be achieved.

A number of previous studies show the significance of the riser dynamics to public safety. Irani et al. (1987) performed the dynamic analyses of risers with steady internal flow and nutation dampers in three dimensions using an energy approach and the finite element method. The results showed that the internal flow reduced the overall stiffness of the marine risers. It also gave a negative damping mechanism to the riser dynamic behaviour. A similar study was done using asymptotic approach together with a finite element method (Moe and Chucheepsakul, 1988). It was found that the natural frequencies were slightly reduced at a low internal flow speed but significantly trend could be observed at very high flow speed.