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Investigation of Sway—Yaw Motions of Deepwater FPSOs

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Abstract

Measurement and analysis of the stability of Single Point Moored (SPM) vessels has been conducted over the last few decades, resulting in well established analysis techniques for the assessment during conceptual design of the stability of the motions of SPM's on their moorings. However during the course of a recent conceptual study for a permanently moored deep water FPSO, large unstable coupled sway-yaw motions were observed during time domain verification analyses. Similar fishtailing responses have been observed in reality at a number of SPMs and extensive studies have been undertaken [7, 9]. However the motions observed during the time domain analyses were so severe that the proposed mooring system would not have been able to hold the FPSO on station.

This unstable behaviour was not predicted by the well established stability analysis techniques. Review of the literature and a programme of sensitivity tests of the numerical modelling approach indicated that the observed sway-yaw response was not an artefact of assumptions and simplifications in the moored system stability model. The assumption that the stability of the mooring system could be assessed from the steady environmental forces was found to have the greatest influence on the observed moored system stability.

Further numerical study indicated the existence of a bifurcation instability in the mooring system configuration not predicted by well established stability analysis techniques.

The analyses reported here indicated that when developing mooring systems for deep water FPSOs, ignoring the destabilising effect of time varying forces in the stability analysis could result in a mooring design unfit for service.

Introduction

As the search for oil moves into deeper water Floating Production Storage and Offloading (FPSO) vessels are becoming popular as a means of developing marginal fields. FPSOs use station-keeping systems such as moorings in order to operate. These mooring systems are often Single Point Moorings (SPMs), which allow the FPSO to align with the dominant environment direction. This ability to align the vessel reduces the load on the mooring system, and is required in all but the most benign environments.

Over the past 30 years, substantial knowledge of the response of moored SPMs has been gathered from numerical and scale model tests and from a number of full scale measurements. This experience has resulted the development of in a number of commonly used techniques to analyse the response of SPMs.

Typical analysis techniques include the assessment of mooring system stability when exposed to severe environments. In shallow water it is feasible to make an FPSO capable of disconnecting for severe weather conditions such as the passage of a hurricane or cyclone. However, in deepwater disconnectable system behaviour becomes problematic due to high riser payloads and internal riser fluid content variability due to flow assurance issues. Thus FPSO developments in deepwater may require SPMs to remain permanently moored in cyclonic/hurricane prone regions, such as the Gulf of Mexico (GOM).

When SPMs are exposed to severe environments it becomes more likely that they may exhibit unstable motions of the classic fishtailing or bifurcation type. Aghamohammadi [1] discussed the nature of these bifurcations and how they may manifest themselves at full scale (e.g. aero elastic flutter). In many instances, the unstable cycles that occur at a bifurcation may stabilise as large amplitude cycles at a cyclic fold. These unstable motions arise from the asymmetry in the restoring force matrix caused by the interaction between fluid loading and mooring stiffness [2].

More recently Kaalstad et al. [3] undertook a series of investigations of an FPSO moored in 2,000m of water. Their analyses showed that FPSO directional instability could occur in the 100 year winter storm (H_s = 7.8m) and the simulations were run with transverse linear springs representing a 3,000HP bow thruster in order to achieve a stable response. However The fishtailing instability tendency was found to be minimal in the model tests. Given the nature of the system response, and the extreme sensitivity of such systems to initial conditions and sources of damping, difficulties with Reynolds number scaling in the 1:88.9 scale model test may have masked what could be a real issue at full scale. Alternatively, as found by Brotons and Jean [4], the instability in the numerical model could simply be the result of underestimating the contribution of the numerous sources of damping in the numerical model.