Internal Flow-Induced Instability Analysis of Catenary Risers

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ABSTRACT

Offshore production and export risers in deep-water oil and gas applications are highly slender and flexible structures subject to environmental and operational loading conditions. In particular, steel catenary risers with variable local curvatures and inclinations have been widely considered by industry as a technologically and economically viable solution for deep waters. Nevertheless, the mechanism of dynamic instability for curved bendable pipes transporting flows has not been properly investigated in the literature despite such practical and theoretical importance. In this study, the dynamic response and stability of slender catenary riser pipes conveying internal flows with varying velocities are investigated by using a finite element-based continuum pipe model.

This work formulates the system equations of motion by making use of the Hamilton's principles to cast the flow-carrying curved pipe dynamics. Numerical in-house tools are developed and employed to examine the natural vibration characteristics of the free-spanning catenary pipes with pinned-pinned boundary conditions. Two numerical approaches are implemented for modelling the flexible pipe's dynamic stiffness from its initial static equilibrium. The first one is based on the straight beam elements relying on a linearized process in considering the additional dynamic stretching. The second one makes use of actual catenary elements with a rapidly converging solution process. The resulting eigenvalue problem in a complex-valued format is used to analyse potential divergence and flutter unstable modes and associated natural frequencies of curved pipes transporting uniform flows. The effects of pipe sagging or curvatures and the contribution of Coriolis and Centrifugal fluid forces are examined for increasing flow speeds, in comparison with straight pipe cases.

It is found that the effects of pipe curvatures and inclinations play a significant role in the dynamic instability of a long catenary riser transporting flows. Theories and numerical strategies present in this study are being extended to the multiphase flow applications where intermittent slug liquid-gas flows become problematic for subsea piping systems. This paper will also set the foundation for modelling of slug flows with a cavalcade of slug units travelling in a catenary riser.

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