On suppression of vortex-induced vibrations of a marine riser conveying fluid by means of variation of the convection speed

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Marine risers often vibrate in currents due to a phenomenon known as vortex-induced vibration (VIV). This vibration is triggered by a vortex shedding that takes place when water flows past a riser with a sufficiently high speed. If the vortex shedding frequency happens to be close to one of the natural frequencies of the riser, the latter begins to oscillate with growing amplitude. The larger the amplitude of vibration, the stronger the effect of the riser motion on the wake composed of the vortices. This riser-wake interaction results in synchronisation of the vortex shedding by the riser in terms of both the frequency and distribution along the riser. In this manner a coherent vortex shedding pattern is achieved that alternates at one of the natural frequencies of the riser in synchrony with a quasi-harmonic sustained vibration of the riser with perceptible amplitude.

If not mitigated, VIV can accelerate fatigue of the riser material and, consequently, reduce the service life of the riser. To avoid this, various passive and active suppression techniques are applied in the offshore industry. As a rule, passive suppression is attempted by means of installation of helical strakes or fairings on the risers. Both techniques are reasonably effective but have several notable limitations.

Presented in this paper is a principally different technique of VIV suppression which can be applied to risers in the operation mode, i.e. when they convey fluid (hydrocarbons or water). It is an active suppression technique, whose main advantage seems to be in the capability of VIV suppression without any variation of the outer surface of the riser.

It is proposed to modify the flow through the riser such as to introduce an effective damping sufficient to prevent the synchronisation of riser vibration with the vortices. The effective damping can be introduced by means of a periodic variation of the flow speed through the riser. It is well-known that such a periodicity of the flow can destabilize the riser. However, it can also stabilise it and it is this stabilisation effect that is proposed to use for VIV prevention.

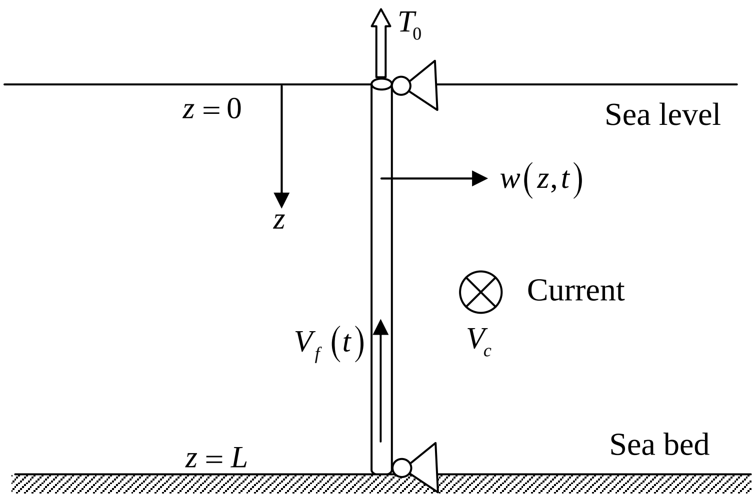

Figure 1. A sketch of a vertical, submerged, top-tensioned riser in uniform out-of-plane flow.

A simple riser configuration is considered in this paper as shown in Figure 1. The riser is assumed to be vertical, fully submerged, top-tensioned and simply supported against the bending motion both at the top and at the bottom. It is also assumed that the current is unidirectional, uniform and its velocity

V_c is normal to the plane of Figure 1. Finally, it is assumed that the riser is slender and its motion takes place predominantly in one plane (the plane of Figure 1) and the effect of the drag-induced out-of-plane displacement on the in-plane riser dynamics can be neglected.

The riser is modelled using the Euler-Bernoulli model for a beam in bending. The plug-flow model [1] is employed to describe the conveyed fluid. The flow past the riser and its interaction with the riser are accounted for by means of a wake oscillator model. The basic idea behind this model is, as noted by Birkhoff [2], that 'the wake swings from side to side, somewhat like the tail of a swimming fish' and can be characterized by a dimensionless wake variable $q(z,t)$. A recent version of the wake oscillator model proposed in [3] is employed in this paper, according to which the governing equations for the riser-wake model can be written as

$$EI\frac{\partial^4 u}{\partial z^4}-\frac{\partial}{\partial z}\left(T_{\text{eff}}\frac{\partial u}{\partial z}\right)+m_f V_f^2\frac{\partial^2 u}{\partial z^2}+2m_f V_f\frac{\partial^2 u}{\partial z\partial t}+\frac{dV_f}{dt}\frac{\partial u}{\partial z}+\left(\frac{\pi D_{\text{i}}^2}{4}\rho_f+M\right)\frac{\partial^2 u}{\partial t^2}=\frac{1}{2}\rho_f D_{\text{e}}V_c^2 C_{Vu},$$

(1)

$$\frac{\partial^2 q}{\partial t^2}+\varepsilon\omega_s\left(q^2-1\right)\frac{\partial q}{\partial t}+\omega_s^2 q=\frac{A}{D}\frac{\partial^2 u}{\partial t^2},\qquad \omega_s=2\pi\text{St}V_c/D_{\text{e}} \tag{2}$$

$$C_{Vu}=\left(-2\pi\text{St}\hat{C}_{x0}^0\frac{\partial u}{\partial t}+\frac{1}{2}\hat{C}_{u1}^0 q\right)\sqrt{1+4\pi^2\text{St}^2\left(\frac{\partial u}{\partial t}\right)^2}, \tag{3}$$

$$T_{\text{eff}}(z)=\frac{1}{4\pi}\rho_r g\left(D_{\text{e}}^2-D_{\text{i}}^2\right)(L-z), \tag{4}$$

$$z=0:\quad u=0,\ \frac{\partial^2 u}{\partial z^2}=0;\quad z=L:\quad u=0,\ \frac{\partial^2 u}{\partial z^2}=0. \tag{5}$$

Equations (1) and (2) govern the coupled dynamics of the fluid conveying riser characterized by a horizontal displacement $u(z,t)$ and the wake. Equation (3) gives the dependence of the force the riser is subject to in the alternating vortices. Equation (4) gives an expression for the effective tension $T_{\text{eff}}(z)$ in the riser assuming that the water flow through the riser does not influence the tension but taking into account the effect of hydrostatic pressure both from inside and outside the riser. Equation (5) specifies the boundary conditions for the riser. The wake is assumed to vary along the riser only due to the riser vibration and, therefore, its governing equation does not need to be supplemented by the boundary conditions. The notations used in equations (1)-(5) are explained in [3] and [4].

In the presentation results will be discussed of the dynamic stability analysis of the linearized system assuming that the velocity V_f of the flow through the riser is given as $V_f=V_f^0\sin(\Omega t)$. Parameters of the conveyed flow are identified, which prevent VIV from occurring. Secondly, results of a nonlinear numerical analysis of the system will be presented with the focus on the effect of small variation in the conveyed flow speed on the amplitude of VIV should the latter be not prevented by the assumed variation.

References

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