A 3D nonlinear reduced-order model of a cantilevered aspirating pipe under VIV

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Abstract. This paper brings a 3D nonlinear reduced-order mathematical model (3D ROM) of a vertical immersed cantilevered flexible pipe aspirating fluid and subjected to transversal external flow. The Modular Modeling Methodology (MMM) conciliates the use of the extended Hamilton Principle for non-material volumes (responsible for modeling the structural dynamics along with the effects due to aspiration of fluid) along with wake-oscillators of the van der Pol Equation type (which represent a phenomenological model for the interaction of the system with the external flow). A root-loci analysis guides the choice of two simulation scenarios based on the value of the internal flow velocity: just below and just beyond the first transition to instability, at small velocity. The external flow velocity, on turn, is considered over a range where the second mode of vibration is fully excitable. The results so obtained show that the vibration amplitude due to VIV is not significantly affected by the internal flow.

About the reduced-order nonlinear model

The present paper aims at presenting a 3D reduced-order model for an immersed cantilevered flexible pipe aspirating fluid under VIV, following a similar procedure to the one adopted by [4], in which the equations of motion for the 'discharging pipe case' have been derived according to the Modular Modeling Methodology (MMM). The generalized extended Hamilton principle for non-material volumes is applied [1] in the derivation of a kinematically exact structural model a flexible pipe aspirating fluid. The usual plug-flow hypothesis, also adopted in the discharging pipe case, is assumed to be valid except at the pipe entrance. In this case, a modified version of [2] model is adopted and an integral parameter χ, related to the geometry of the internal flow velocity profile close to the inlet section is introduced ($\chi \rightarrow 1$ as the velocity profile at the inlet section comes close to become uniform). Regarding the interaction with the external flow, beyond the added mass effect, non conservative generalized forces due to vortex shedding are simply modeled by a wake-oscillator model of the van der Pol Equation type, inspired by the work of [3], which originally treated a rigid cylinder under single-dof VIV. For the sake of adapting this modeling scheme to the present analysis, it is assumed that short segments of the flexible pipe would behave similarly to a rigid pipe in terms of vortex shedding.

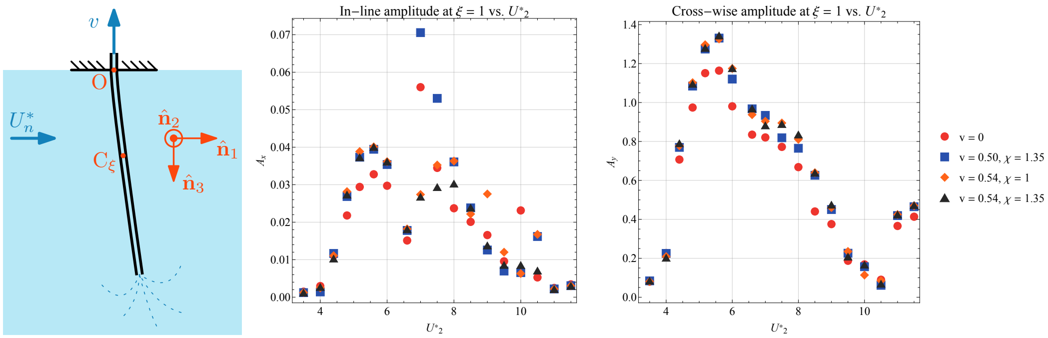

Figure 1: Schematic representation of a submerged cantilevered flexible pipe aspirating fluid and the in-line and cross-wise amplitudes of the oscillations of the center of the inlet section of the pipe as a function of U_2^* for all the analyzed scenarios.

VIV response analysis

From a stability analysis, the critical value for non-dimensional internal flow velocity $\bar{v} = 0.52$, above which the vertical equilibrium configuration of the aspirating pipe becomes unstable, is identified. Thus, the response of the non-linear system under VIV is assessed by performing numerical simulations in the following scenarios: (i) $v = 0$ (absence of internal flow); (ii) $v = 0.50$ (slightly below $\bar{v}$); (iii) $v = 0.54$ (slightly above $\bar{v}$). In this latter case the dynamic response is investigated by considering both $\chi = 1$ and $\chi = 1.35$. For each scenario, 18 numerical simulations were performed, varying the external flow free-stream speeds over a range in which the respective second mode of vibration is fully excitable ($3.5 \leq U_2^* \leq 11.5$). The results so obtained, illustrated in Fig. 1, show that the vibration amplitude due to VIV is not significantly affected by the internal flow.

References

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