NUMERICAL SIMULATIONS OF VIV OF A FLEXIBLE CYLINDER WITH VARYING AXIAL TENSIONS

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Flexible cylindrical structures are widely used in the offshore scenario, such as deep-sea risers and tethers. Vortex-induced vibration of flexible cylinders has been extensively studied in the past decades. In actual production, the periodic heave motion of floating structures may generate a periodic impact towards the top-tensioned riser, which leads to a periodic tension. Because of the dynamic effect, the cylinder's natural characteristics change over time resulting in a continuous modal transition. Under the effect of time-varying tensions, the mechanism of vibration is different from the simple VIV problem. Previous researches have made great contributions on the stability problem [1] and vibration mode [2].

In this paper, numerical simulations are conducted by the in-house CFD code viv-FOAM-SJTU, which is developed based on the pimpeDyMFOAM solver attached to OpenFOAM. For a long flexible structure, a direct three-dimensional simulation of the flow field is accurate but cost too many resources. Instead, a simplified strip method is applied for solving CFD simulations of supramaximal computational domain. It owns high computational efficiency and the computational accuracy is reliable, which has been verified through related researches. The reliability of the viv-FOAM-SJTU solver has been validated by Duan and Wan [3] and Fu et al [4].

Several strips are distributed equally along the cylinder and simulations of fluid field are performed based on RANS equations and SST k-ω turbulence model. As for the structural field, the Euler-Bernoulli beam model and finite element method is used. Interpolation is used to realize the transformation of data between the fluid field and the structure field. The strip model and the procedure of fluid-structure interaction is shown in Fig. 1. The schematic diagram of the viv-FOAM-SJTU solver is shown in Fig. 2.

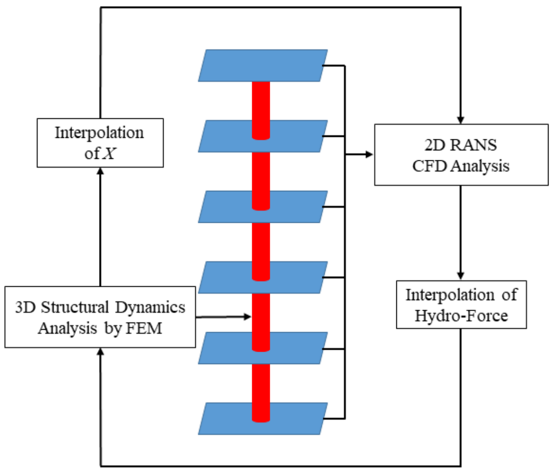


Fig 1: Schematic diagram of of the strip model and fluid-structure interaction

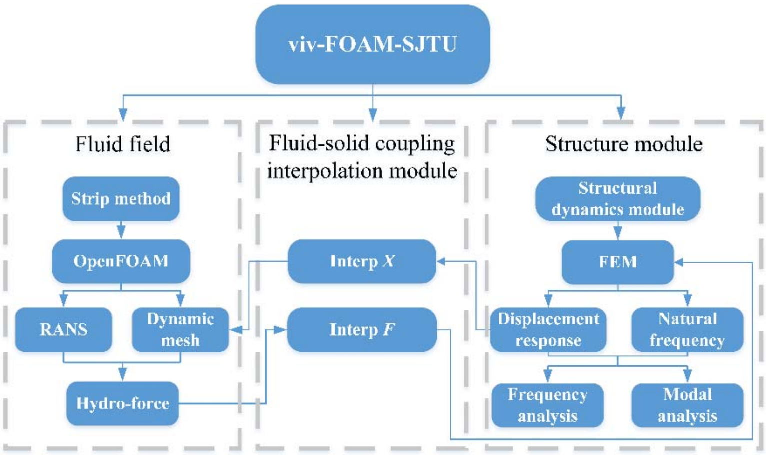


Fig 2: Schematic diagram of of the viv-FOAM-SJTU solver

In this paper, the flexible cylinder is simulated as a beam simply supported at both ends. The axial tension changes periodically and is a parametric excitation of the cylinder model. Twenty strips are set equidistantly along the cylinder with the same computational domain. The computational model and the initial mesh are shown in Fig. 3. The axial tension is assumed to change harmonically. Main parameters of the model and cases are listed in table1 and table 2. The first case is a VIV problem with constant tension and is chosen as a comparison. The second case is VIV of a flexible cylinder with time-varying tension. The frequency of the varying tension is 1.1410Hz, namely the first order natural frequency.

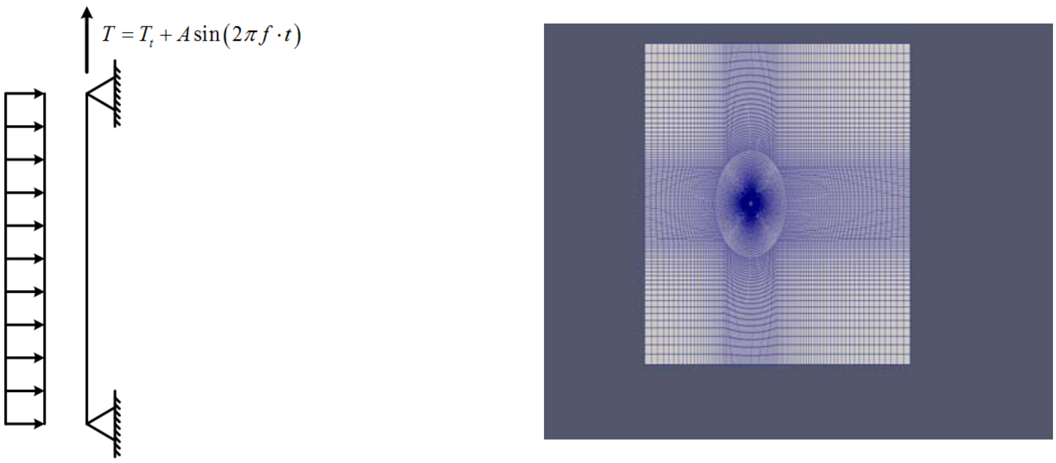


Fig 3: Strip model and the initial mesh on each strip

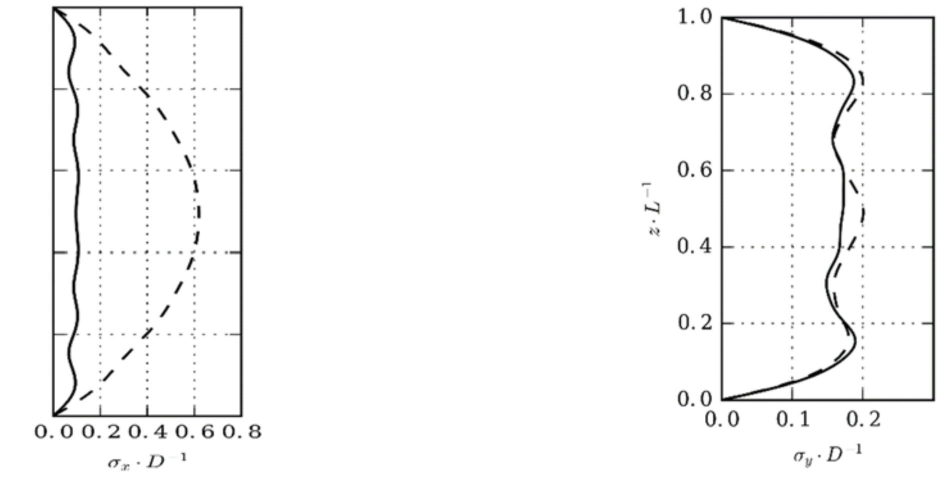
Table 1. Main parameters of the computational model

Parameter	Symbol	Value	Unit
Diameter	*D*	0.028	*m*
Length	*L*	14	*m*
Mass Ratio	*m**	2.4	-
Bending Stiffness	*EI*	29.88	$N{\cdot}m^2$
Flow Speed	*U*	0.4	*m/s*
Static Top Tension	*Tt*	1610	*N*
Varying Tension Amplitude	*A*	0/500	*N*
Varying Tension Frequency	*f*	1.1410/3.4367	*Hz*

Table 2. Main parameters of the cases

Case No.	Pre-Tension (N)	Varying Tension Amplitude (N)	Varying Tension Frequency (Hz)
Case 1	1610	0	0
Case 2	1610	500	1.1410

Fig. 4 compares the standard deviation between the two cases in both in-line and cross-flow directions. The solid and dashed lines represent Case 1 and Case 2, respectively. For the in-line vibration, effect of the varying tension is obvious. The maximum STD displacements is about 0.1 for Case 1 and over 0.6 for Case 2, which is caused by internal resonances. In the in-line vibration, the cylinder appears as an arc under the effect of uniform flow, the shape of which is similar to the first mode related to the first order natural frequency. When the tension varies at the first-order frequency at a relatively large amplitude, it inspires the internal resonances. Therefore, an obvious amplification is observed in the Fig. 4(a). For the cross-flow vibration, the amplification effect is little, as shown in Fig. 4(b). This is reasonable because there is no internal resonance for the cross-flow vibration.



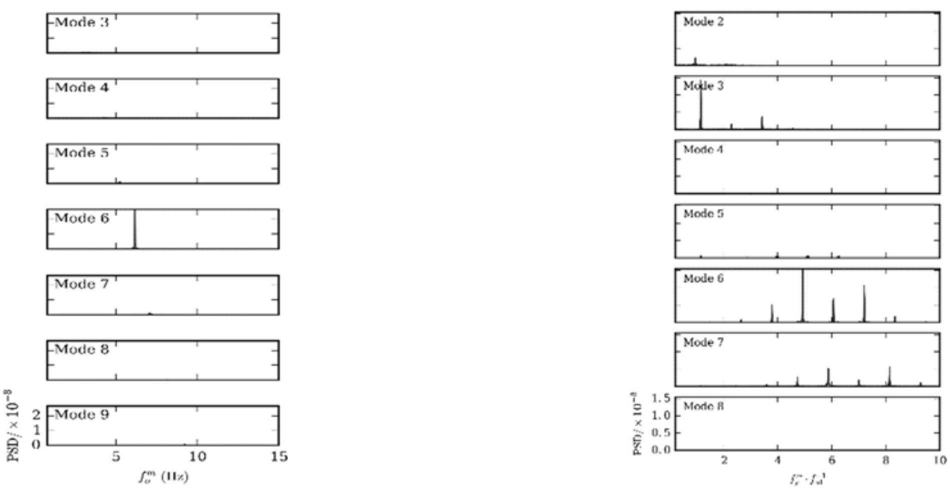
(a) **(b)**

Fig 4: Standard Deviation of the displacements: (a) stands for the in-line vibration; (b) stands for the cross-flow vibration

Fig. 5 shows the comparisons of power spectral density of each mode and displacements at several places along the cylinder model in in-line direction. The frequency component is obtained through FFT algorithm.

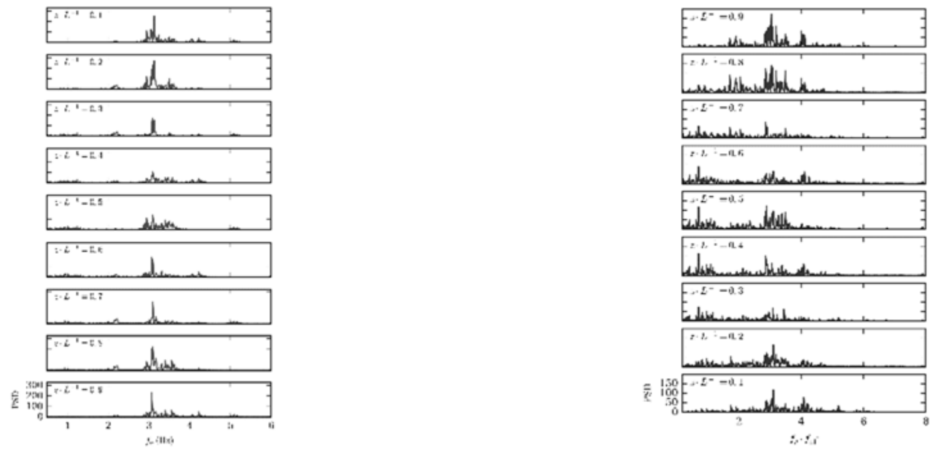
Under the effect of the varying tension, multi-modal vibrations are inspired. Previous researches have shown that a long flexible cylinder tends to vibrate at various modes (Willden and Graham [5] and Vandiver et al [6]). The varying tension inspires the multi-modal vibration of the cylinder model. The frequency component at the third mode equals to the frequency of the varying tension.

Fig. 6 show the comparisons in cross-flow direction. Effects of the varying tension are not the same as the in-line vibration. The sub-harmonic vibration appears in the middle part of the cylinder (Fig. 6) which is a typical phenomenon in the parametric excitations. It reflects the nonlinearity of the system. Similar to the in-line vibration, more frequency components appear in the power spectral density figure. However, it is different that the varying tension do not dominate the vibration frequency. The original VIV frequency components are still obvious.



(a) Case1 **(b) Case2**

Fig 5: Comparison of modal power spectral density between case 1 and case 2 in the in-line direction



(a) Case1 **(b) Case2**

Fig 6: Comparison of power spectral density between case 1 and case 2 in the cross-flow direction

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