DYNAMIC RESPONSE OF A FLEXIBLE RISER SINUSOIDAL EXCITED AT ITS TOP END USING THE QUASI-STEADY MODEL

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1. Introduction

To accurately design marine risers it is important to predict the amount and nature of the Vortex-Induced Vibrations (VIV) that the riser will suffer during its useful life. Fatigue damage, which is commonly associated with VIV, can be predicted when the dynamic behavior of a flexible riser is well represented by a FE model, but it is still challenging to develop a reliable FE model for flexible risers due to the complex nature of fluid-structure interaction. This paper presents a numerical procedure to compute the transverse lift forces that are acting on a flexible riser using the quasi-steady model. The simulation results will be compared with experimental data.

2. Experimental Models

The first experimental riser model presented in this paper was developed by Hong and Koterayama [1]. For this model a new analytical scheme was developed in [1] without considering VIV; only drag and added mass forces were taken into account. The second flexible riser model was developed by Senga and Koterayama [2]; this riser model is similar to the one previously used in [1] and considers VIV. Experimental data were compared with numerical results from the new analytical scheme [2]. The model has a length of 6.5 m, Young's modulus of 8.847 MPa, outer diameter of 0.0225 m, inner diameter of 0.0127 m and density of 1476 kg/m^3. The model has a bottom weight in order to keep straight the riser during the dynamic tests. The bottom weight has a diameter of 0.034 m, a total length of 0.093 m and a weight in water of 3.489 N. The model is excited by a sinusoidal force oscillation motion with amplitude of 0.1 m and force oscillation period of 8 seconds and is simply supported at its top end and free supported at its bottom end.

3. Modeling of the Transverse Lift Force

The transverse lift force is analytically represented by the quasi-steady model presented by Obasaju *et al.* [3]. This model assumes that regular shedding of vortices produces a sinusoidal force (transverse lift force), which is proportional to the square of the in-line maximum velocity as shown in Eq. (1).

$$F_L(t) = \frac{1}{2}\rho U_0^{\ 2} D C_{L\max} \sin(2\pi t \omega_L + \psi) \tag{1}$$

where F_L is the lift force per unit length of the structure, U_0 is the relative in-line maximum velocity, C_{Lmax} is the maximum lift coefficient, ω_L, is the dominant frequency and ϕ is the phase angle. The dominant frequency mainly depends on the Keulegan-Carpenter number (KC) when the Strouhal number $S_t = 0.2$. The main assumption in the quasi-steady model is that static fluid forces measured on a stationary body can be used to approximate dynamic fluid forces on an oscillating body.

4. Numerical Implementation

The commercial software ABAQUS [4] is used to build the FE model. The riser model is assembled using 20 PIPE elements and one CIRC element is used for the bottom weight. At the water level there is no horizontal velocity component and geometric nonlinear procedure is used to load the riser using its self-weight during the static step; then, the drag force and the fluid inertia load are applied to the riser during the dynamic step. For this numerical implementation, the mean drag coefficients and the added mass coefficients are obtained from experimental data [1] and the maximum lift coefficients from [3]. An in-house FORTRAN subroutine was developed by the authors in order to input the transverse lift force to the FE model according to the quasi-steady model.

Keywords: flexible riser, transverse force, quasi-steady model, dominant frequency.
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5. Results and Discussion

The experimental and analytical results obtained by Hong and Koterayama [1] are shown in fig. 1 and the simulation results using the quasi-steady model are shown in fig. 2. Good agreement is observed for the selected periods of oscillation, the in-line response is accurately represented by the numerical simulation. The flexible riser model presented in [2] is sinusoidal excited at Reynolds numbers (Re) up to 2000 and Keulegan-Carpenter (KC) numbers up to 28. This regime is named the third vortex ($22 < KC < 30$) by Obasaju *et al.* [3]. In this regime three full vortices are shed per half-cycle and experimental studies had shown that the dominant frequency is 4 times the in-line oscillating frequency. The maximum in-line velocities for each of the 20 PIPE elements are used to compute the dominant frequencies. The experimental and analytical results presented in [2] agree with the simulation results using the quasi-steady model. The transverse response of the riser model [2] at 4.31-meter depth is shown in fig. 3 and the simulation results in fig. 4.

6. Conclusions and Future Directions

A practical approach was presented in this paper to model the transverse (lift) force in the third vortex regime. Good analytical representation can be achieve using the dominant frequency instead of the instant shedding frequency, which involves the computation of the instant velocity for each section. The simulation results presented in this paper show good agreement with the experimental data provided by two experimental models. Further work is needed to study the quasi-steady model when large structure-interaction is dominant.

Acknowledgments

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References

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Figures

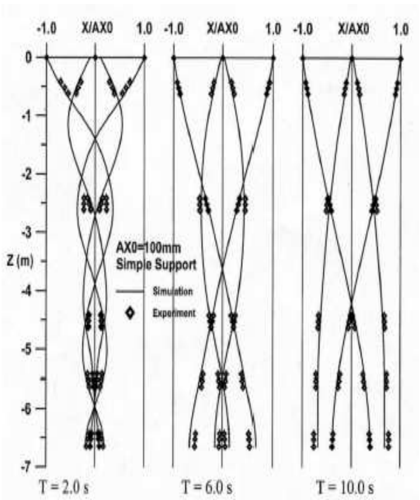

Fig. 1 Experimental and Analytical Results

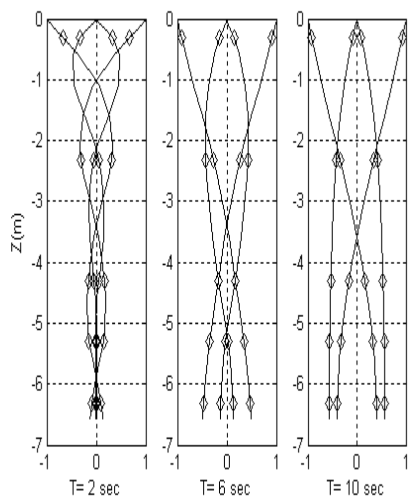

Fig. 2 Simulation Results

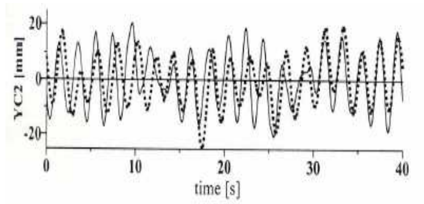

Fig. 3 Experimental and Analytical Results [2]

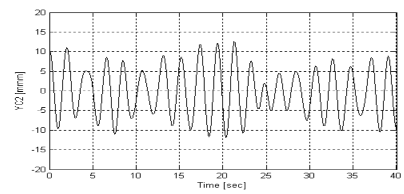

Fig. 4 Simulation Results (quasi-steady theory)