NUMERICAL PREDICTION OF DYNAMIC RESPONSE OF OSCILLATING FLEXIBLE RISERS

Kyoto University Student Member Carlos Alberto RIVEROS
Kyoto University Member Tomoaki UTSUNOMIYA
National Maritime Research Institute Katsuya MAEDA
JAMSTEC Kazuaki ITOH

1. Introduction

Current industry efforts target the use of composite materials to reduce the weight of the flexible slender pipe (riser), which is widely used to transport oil from the seabed to offshore facilities. The main objective of this tendency is to provide a new type of riser that can extract the oil at water depths of more than 2000 m. Nevertheless, the reduced weight shifts the dynamic response of the riser into a range where fluid-structure interaction problems increase. In this paper, a response prediction model for risers is presented and experimentally validated using data from a 20-meter riser model having a low mass-ratio (calculated as the mass of the cylinder divided by the mass of the fluid displaced).

2. Response Prediction Model

The procedure presented by Riveros et al. [1] is used herein. In Eq. 1, the riser is idealized as a beam with low flexural stiffness. A Cartesian reference is defined in the *x*-axis by the force motion at the top end of the riser, the *z*-axis is defined in the direction of the riser's axis and the *y*-axis is perpendicular to both.

$$EI\frac{\partial^4 u_{x,y}(z,t)}{\partial z^4}-\frac{\partial}{\partial z}\left[\left(T_t-w\left(L-z\right)\right)\frac{\partial u_{x,y}(z,t)}{\partial z}\right]+c_0\frac{\partial u_{x,y}(z,t)}{\partial t}+m_0\frac{\partial^2 u_{x,y}(z,t)}{\partial t^2}=F_{T_{x,y}}(z,t) \quad (1)$$

where m_0 is the mass of the riser per unit length, $u_{x,y}(z,t)$ is the deflection, c_0 is the damping coefficient, EI is the flexural stiffness, T_t is the tension applied at the top of the riser, L is the length of the riser and w is the submerged weight. The external fluid force is $F_{Tx,y}$. The in-line force is computed according to Carberry et al. [2] as shown in Eq. 2.

$$F_{T_x}(z,t)=\rho SC_m\dot{U}_1-\rho SC_i\ddot{u}_x+\frac{1}{2}\rho D(U_1-\dot{u}_x)\left|U_1-\dot{u}_x\right|\left[C_{Dmean}+C_D sin\left(2\left(2\pi tf_L+\phi_{drag}\right)\right)\right] \quad (2)$$

where ρ is the density of the surrounding fluid, S is the cross-sectional area of the displaced fluid, U_1 is the steady velocity of the fluid in the *x*-axis and D is the diameter of the riser. The mean drag coefficient is denoted by C_{Dmean}, the fluctuating drag coefficient by C_D, the inertia coefficient by C_m and the added-mass coefficient by C_i. f_L is the dominant frequency (most dominant frequency in the *y*-axis or cross-flow direction). φ_{drag} is the phase of the drag with respect to the cylinder's displacement in the cross-flow direction. The transverse force can be computed as shown in Eq. 3.

$$F_{T_y}(z,t)=\frac{1}{2}\rho DU_0{}^2C_L sin\left(2\pi tf_L+\phi_{lift}\right) \quad (3)$$

U_0 is the relative in-line maximum velocity. C_L is the lift coefficient and φ_{lift} is the phase with respect to the cross-flow displacement. C_L varies with the amplitude of the cross-flow motion (A_y) according to Blevins [3] as shown in Eq. 4.

$$C_L=0.35+0.6\left(\frac{A_y}{D}\right)-0.93\left(\frac{A_y}{D}\right)^2 \quad (4)$$

Finally, in order to consider the increment of drag forces during lock-in events, an increased mean drag coefficient (C_{Dinc}) model is selected based on an empirical formulation presented by Khalak and Williamson [4] as shown in Eq. 5.

$$\frac{C_{Dinc}}{C_{Dmean}}=1.0+2.0\left(\frac{A_y}{D}\right) \quad (5)$$

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Address: Katsura Campus, Nishikyo-ku, Kyoto, 615-8540, Japan; Tel: 075-383-3164, Fax: 075-383-3163
Email: criveros@mbox.kudpc.kyoto-u.ac.jp, utsunomi@mbox.kudpc.kyoto-u.ac.jp, kmaeda@nmri.go.jp, itohk@jamstec.go.jp

3. Experimental Validation

The experimental validation is carried out in the Integrated Laboratory for Marine Environmental Protection (National Maritime Research Institute). The response prediction model presented in this paper is experimentally validated using a 20-meter model sinusoidally excited along the *x*-axis with amplitude of 0.08 m and period of 2 seconds. The model is excited in still water and steel bars are added to the riser model in order to increase its self-weight. The total weight of the riser, including the steel bars, is 68.14N. Pinned connections are used at its both ends and the tension force, applied at its top end, corresponds to 6.47Kgf. The riser model is made of polyoxymethylene having an outer diameter of 0.016 m, inner diameter of 0.0108 m, density of 1410 Kg/m^3 and Young's modulus of 2.94 MPa. The proposed prediction model is numerically implemented using the following parameters C_D=0.2, φ_{drag}=0 and φ_{lift}=0. Further information related to the numerical procedure employed in this paper can be found in Riveros et al. [1]. Finally, FFT amplitudes are computed for all the sections of the riser in both in-line and cross-flow directions and depicted in Figs. 1 and 2, respectively. Time series response is shown for *z*=-9 m and -12 m in Fig. 3.

4. Conclusions

In-line response is well predicted. On the other hand, it is possible to observe significant differences in the cross-flow direction due to the non-sinusoidal response of the riser. Actually, accurate prediction of the cross-flow response in flexible risers is still challenging due to its highly nonlinear nature. In addition, the assumption that only one frequency dominates the cross-flow response may introduce considerable deviations in its numerical calculation.

References

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Figures

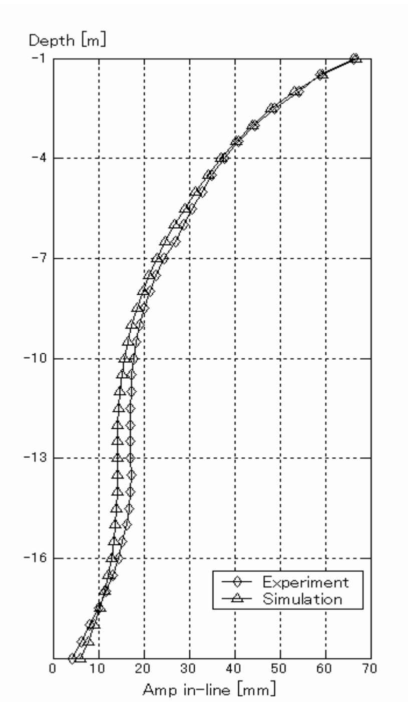

Fig. 1 FFT Amplitudes In-line

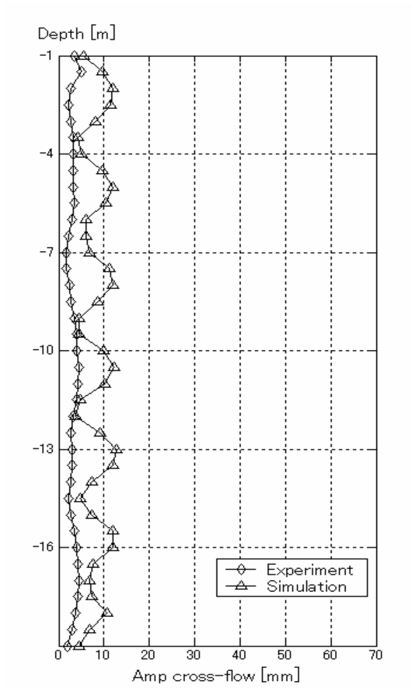

Fig. 2 FFT Amplitudes Cross-flow

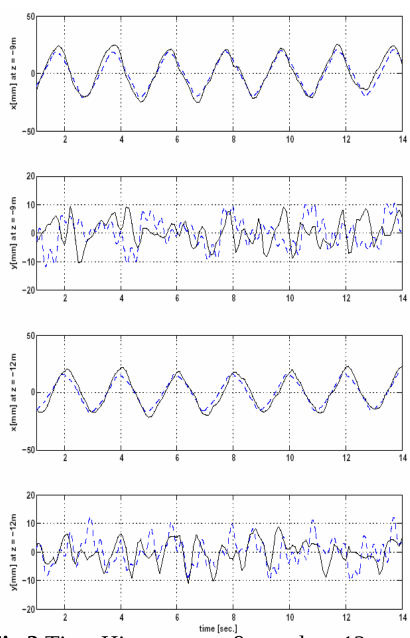

Fig.3 Time History at *z*=-9m and *z*=-12m

---- Simulation ___Experiment