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II SIMPÓSIO DE MODELAGEM COMPUTACIONAL EM CIÊNCIA E TECNOLOGIA DO PIAUÍ

Numerical Modeling Of Partially Submerged Beam-column

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Introduction

The offshore industry often employs excessive structural material due to the unpredictable nature of the marine environment (Fig. 1). Submerged structures are subject to various hydrodynamic forces, including drag, inertia, added mass, diffraction, Froude-Krylov, and wave slamming forces. This study aims to contribute to reducing over-dimensioning, thereby lowering manufacturing costs and CO_2 emissions. The Morison equation is applied to estimate wave-induced forces, and the structure is modeled using a beam-column element.

Methodology

The structure was modeled as a cantilever beam-column partially submerged in a marine environment, and its dynamic behavior was analyzed in both time and frequency domains, focusing on movements at the free end. Hydrodynamic loading was simulated using the Morison equation and a stochastic wave spectrum to represent ocean randomness. This semi-empirical formulation consists of two main components: the inertia force and the drag force, with the latter typically dominating. The normal component of the Morison equation, acting perpendicularly to the cylinder's axis, is expressed as::

$$f^n(x,t) = C_D \rho_f r\left(-w_y\theta + \dot{u}\theta + w_x + U_c - \dot{v}\right)\left|-w_y\theta + \dot{u}\theta + w_x + U_c - \dot{v}\right| \\ + C_M \rho_f \pi r^2\left(\dot{w}_y - \dot{w}_x\theta\right).$$

The term f^n represents the distributed force on the cylinder and depends on hydrodynamic parameters such as inertia and drag coefficients, cylinder radius, water density, flow velocity, and wave particle velocity. The variables θ, u, and v correspond to rotation, axial, and transverse displacements, respectively.

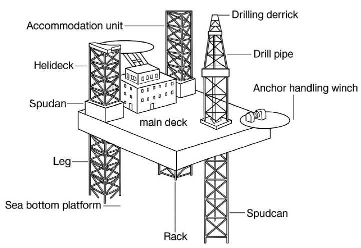

Fig. 1: Offshore jacket type.

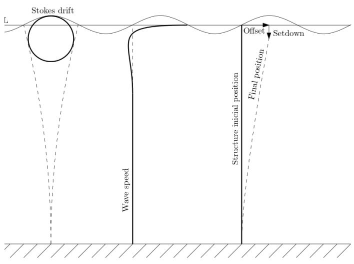

Fig. 2: Structure displacement and wave speed.

The structural response was evaluated using a Timoshenko beam-column element, formulated through the Finite Element Method (FEM) to derive the stiffness and mass matrices. To solve the equation of motion under Morison-type loading, a predictor-corrector version of the Newmark-beta method well-suited for nonlinear systems was applied to solve the equation of motion:

$$M\ddot{x} + Kx = f^n.$$

Results

The results show the dynamic response at the free end of the cantilever beam-column, considering both translational and rotational degrees of freedom in the time and frequency domains. Figures 3 and 4 present the time histories of displacement, velocity, and acceleration for the transverse and rotational motions, respectively. Figures 5 and 6 display the corresponding phase plots, highlighting the system's dynamic trajectory in phase space. The frequency content of the transverse displacement is shown in Figure 7, with a zoomed-in view of its low-frequency range in Figure 8. Figures 9 and 10 show the power spectral density (PSD) of the rotational response and its detailed behavior in the lower frequency range, confirming the dominance of low-frequency components in the system's behavior.

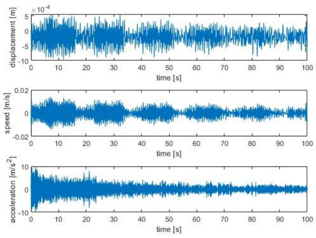

Fig. 3: Transversal time domain response.

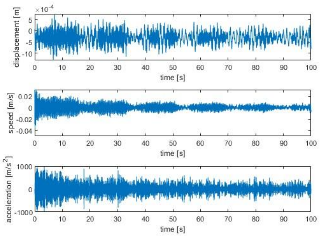

Fig. 4: Rotational time domain response.

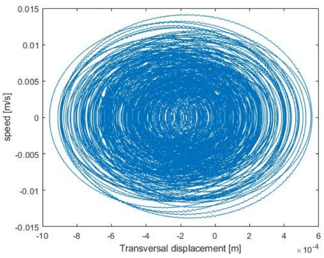

Fig. 5: Transversal phase plot.

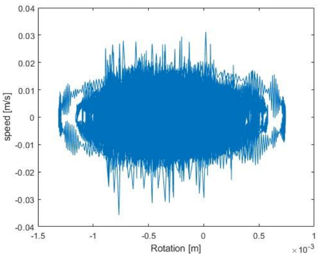

Fig. 6: Rotational phase plot.

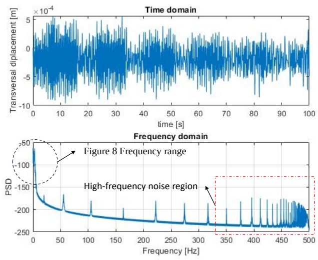

Fig. 7: PSD response of transversal displacement.

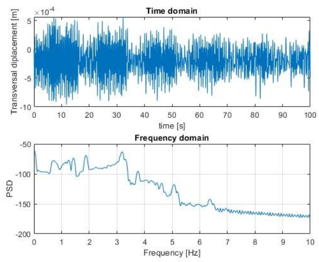

Fig. 8: Zoomed view of transversal PSD.

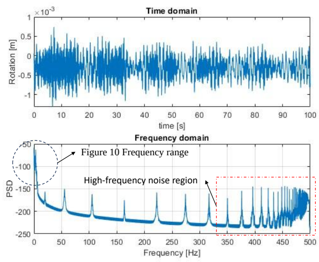

Fig. 9: PSD response of rotational displacement.

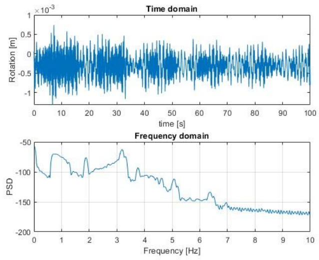

Fig. 10: Zoomed view of rotational PSD.

Conclusion

Offshore structures subjected to hydrodynamic loading exhibit dominant responses in the low-frequency range, while the influence of forced vibrations diminishes at higher frequencies. This behavior is consistent with the literature and reflects the inherent unpredictability of ocean wave excitation.

Due to the random phase angles of ocean waves, the time-domain response lacks full predictability, although general amplitude patterns and phase space behavior can still be identified. Future developments will incorporate the added mass effect and focus on optimizing the topology of a structural framework, aiming to improve performance and reduce material usage.