Application of the Proper Orthogonal Decomposition for the identification of wet modes of marine structures

Dessi D. ([1]), Mariani R. ([2]),

([1]) INSEAN, Istituto per Studi ed Esperienze Architettura Navale - *Dept. of Vibration and Noise*, d.dessi@insean.it **[CORRESPONDING AUTHOR]**

([2]) INSEAN, Istituto per Studi ed Esperienze Architettura Navale - *Dept. of Vibration and Noise*

In marine engineering, there is a renovate effort to provide additional insights on the behaviour of elastic floating structures. Thus, although the theory of hydroelasticity concerning this kind of coupled fluid-structure systems was extensively established in the eighties [1], new challenges relative to the application of the governing equations arise as long as advanced vehicles or constructions appear. In particular, the identification of the so-called wet vibration modes (modes of the structure completely or partially surrounded by the fluid) becomes a relevant information in order to improve the capacity of the model to describe certain phenomena through the definition of the system coefficients. Beside the refinement of the hydroelastic model, involving the evaluation of apparent mass and damping effects due to the water, another goal of this analysis concern the sensing of modifications occurred with respect to a reference condition (caused, for instance, by structural damage).

Using a reduced basis function to describe the observed dynamics is an appealing approach for fluid-structure interaction problems where the number of degrees of freedom may be high and computational costs rise even if the theoretical models involves simplifying assumptions. Among the available techniques, the proper orthogonal decomposition (POD), also known as Karhunem-Loeve decomposition, has recently revealed a useful tool for the analysis of mechanical dynamical system [2][3]. The POD is essentially a multi-variate statistical method which aims to obtain a compact representation of the data. The POD extracts a basis to decompose the data (the proper orthogonal modes, POMs), so that the projection of the data contains as much energy as possible. One of the interesting features of this technique concerns the possibility to relate the POMs to the linear normal modes when the system behaves linearly and information about the mass distribution are provided. On the other hand, since for certain types of marine structures like risers nonlinear effects may be strong under certain conditions, the POD has the possibility to take into account these effects in the basis definition as an intrinsic capability of this method.

Another relevant aspect that the POD shares with other techniques formulated also in the frequency domain, like the Frequency Domain Decomposition [4], is relative to the type of excitation under which the system response is observed. Especially for full-scale structures, the ambient loads (intrinsically of random nature) are the only source of sufficient excitation. In the case of a ship advancing in waves, the stochastic sea spectrum is narrow banded but through the nonlinear transfer function between the wave elevation and water loads there is a relevant enlargement of the spectrum band that in this way covers the frequency range of interest, that is, the frequencies of the lower order structural modes [5].

In the proposed presentation, the identification of the vertical bending modes in water of a ship is performed by analyzing the experimental tests relative to the hydro-elastically scaled physical model in the towing-tank basin, where the bending behaviour was recorded by using response signals provided by either strain-gauges or accelerometers. Particular attention is relative to the determination of the damping of the identified modes, since this may be affected by operative conditions, like the ship speed and the sea characteristics. Other related questions are considered in the development of the present analysis: the significance of the vibration modes when large added-mass variations are present (like in certain operative conditions) and some refinements in the techniques necessary in the case of time-varying system coefficients.

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