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Whipping-based criterion for the identification of slamming events

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ABSTRACT: *In this paper, a new criterion for the identification of slamming events is formulated. This criterion is based on the analysis of the high-frequency response, expressed in terms of the amidships VBM, which occurs after the slams. For this reason, it is named 'whipping' criterion underlining that is based on the analysis of global effects than on the kinematic description of the impact dynamics that was provided by Ochi criterion. Both the new 'whipping' criterion and the Ochi criterion are presented and compared also with respect to their practical application to the experimental data collected in the seakeeping tests with an elastic segmented model.*

KEY WORDS: Bow slamming; Slamming detection; Ochi criterion; Whipping response; Wavelet transform; Hilbert transform.

INTRODUCTION

The analysis of water-impact loads and of the induced vibratory response still plays a relevant role in assessing the structural integrity of ships. This problem has been largely debated in last decades and ship design can nowadays benefit of guidelines issued by classification societies as well as of numerical models and experimental procedures (see Hirdaris et al., 2014). Despite many valuable achievements in this field, recently developed marine vehicles have set new technical queries to researchers and naval architects. A recent example is provided by the Sea-Fighter, an experimental littoral combat ship still under development by the US Navy. It is essentially a twin-hull catamaran with a flat centrebow and with a small waterplane area for each demihull. Designed for reaching speeds up to 50-*kn*, the Sea-Fighter experienced severe slamming impacts during preliminary sea trials which produced damage on the deck (Fu et al., 2009). Even if the possibility of wet-deck slamming occurrence is well known for fast catamarans from a general viewpoint (see Faltinsen, 2006), its importance for new design concepts needs to be assessed with specific investigations (e.g., see Thomas et al., 2003). Another examples is given by ultra-large containership (Senjanovic et al., 2014) where the increased hull flexibility and the lower structural frequencies determine significant springing and whipping phenomena with possible overlapping. The identification of slamming events and the evaluation of their strength plays a fundamental role in the analysis of the correlation between water-entry phenomena and the induced global response of the vessel. Ochi (1964) stated two clear conditions based on kinematics: (*i*) relative motion must exceed the sectional draft; (*ii*) relative velocity at the instant of re-entry must exceed a certain magnitude. According to Ochi, bow-flare slamming does not fall into the set of identified water-entry events because it cannot provide any damage to bottom hull plating, which was one of the main concerns initially. However, also bow-flare slamming might produce large transient vibration of the structure, also known as whipping. Also stern slamming events, which may produce relevant whipping responses in following waves (see Dessi and

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Ciappi, 2010), were not considered by Ochi in the formulation of slamming conditions. The impact dynamics of stern slams is quite different from bow bottom slamming, with the following waves reaching the stern and sometimes impinging the hull, with possibility of air entrapment phenomenon. Thus, the Ochi approach implying the entry velocity as the fundamental parameter and the choice *a priori* of a reference section may lead to wrong conclusions in evaluating the impact severity. If the focus is on the global response, the existence of sequences of consecutive impacts, denoted as ‘clusters’ (see Dessi and Ciappi, 2013), implies that the analysis of a single slam may be not sufficient in establishing a link with the induced response. The existence of slam clusters was not taken into account in early investigations which essentially modelled the slamming phenomenon as a Poisson process (Ochi and Motter, 1973), Mansour and Lozow, 1982), with statistically independent events. In the case of slamming clustering, the response following a single slam is also affected by the fading transients to the slams that have occurred before. This ‘memory’ effect makes more difficult establishing a link between slams and whipping. The above considerations motivate reviewing the Ochi criterion for slamming identification and formulating a new criterion, based on the analysis of the induced ship response, more oriented to the analysis of the global effects due to water impacts. The development of this new criterion, named ‘whipping criterion’, moves from the analysis of the Vertical Bending Moment (VBM) data measured on a segmented model. This physical model, scaling a fast ferry, was tested at the INSEAN towing-tank basin in rough sea conditions. The formulation of the whipping criterion moves from the analysis of the correlation between slams and the following peak in the high-frequency vibratory response. For this reason, the underlying hypotheses as well as the practical implementation of the Ochi criterion (experimental evaluation of the relative motion) have been discussed. For the implementation of the whipping criterion, the high-frequency response is isolated with two different numerical approaches: wavelet analysis and envelope extraction of the filtered VBM response. Particular attention is dedicated to the choice of the high frequency VBM threshold value which discriminates the presence or not of a slam event. It will be shown that this value can be set according to the objective of establishing a strong correlation with Ochi slamming statistics or according to the possible onset of structural damage.

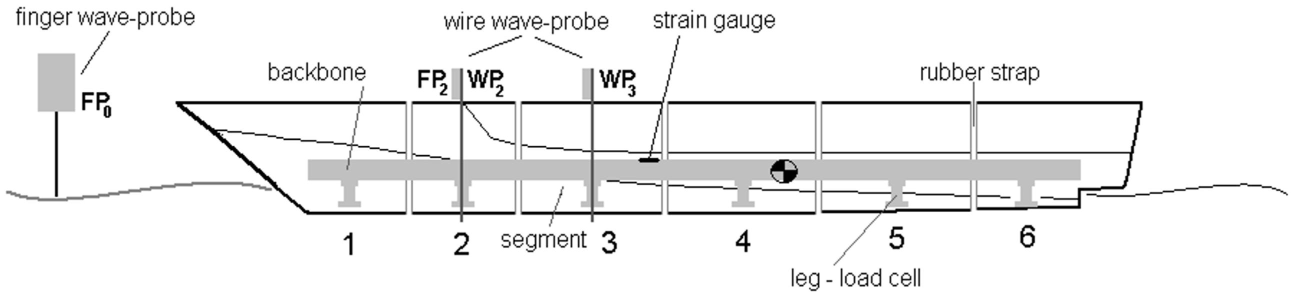

Fig. 1 Schematic representation of the segmented-hull and wave probes layout.

Fig. 2 Side view of the physical model at the end of water-exit phase and wire-probe positions.