CAN MELNIKOV'S METHOD PROVIDE THE RATIONAL ALTERNATIVE TO IMO'S WEATHER CRITERION?

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Extended abstract

An important recent development in the area of dynamic stability of ships is the introduction of the concept of "engineering integrity" and the use of the so-called Melnikov method for defining the unsafe wave environment in terms of ship capsize[1-4]. This approach seems to provide a rational criterion of dynamic stability that is based on the limiting wave slope that can be sustained consistently during the transient stage of a ship's response to oncoming waves of a certain, deterministic or stochastic, type. The key concept of this approach derives from the observation that the safety margin against capsize of a ship is reduced very sharply soon after some critical level of wave-wind excitation is exceeded due to initiation of area loss in this dynamical system's "safe basin" (= the set of initial conditions which lead to a safe ship motion pattern). This critical excitation level, which depends on the ship's damping and restoring characteristics, can be predicted relatively easily through numerical means (either with repetitive basin plotting until the erosion is shown; or, more accurately, with direct numerical identification of the *heteroclinic tangency*, the global bifurcation phenomenon which initiates the loss of area in the basin). Furthermore, analytical or semi-analytical prediction is also possible on the basis of the method of Melnikov. It is very interesting that this method has been shown to be equivalent with an energy balance applied around the heteroclinic orbit of the corresponding Hamiltonian system.

We are currently investigating whether this approach can generate a design criterion for stability that is superior to the "Weather criterion" of IMO[5]. The latter is known to be relatively simplistic in its account of ship dynamics under the action of waves. Furthermore, we are investigating whether it can be used for design optimisation, and furthermore, whether it can be integrated within a risk-based design methodology. Some of the specific issues that will be discussed during the presentation are the following:

a) The "engineering integrity" concept should be workable for arbitrary restoring curves: The characteristics of the integrity curves for the family of 5th order restoring polynomials, $R(x) = x + \alpha x^3 - (1+\alpha)x^5$, have been investigated. In addition, we have determined the critical excitation that initiates basin erosion, as well as the excitation level at 90% "basin integrity" Fig. 1 [6]. However, some questions still remain here: whether the well-known Melnikov formula for cubic-type restoring is a successful predictor (unlike the Melnikov formula for the biased-case which targets the homoclinic tangency event, whose accuracy has been confirmed); and whether it can be modified in order to account for higher-order restoring polynomials.

b) Application to an existing ship: We have performed a comparison of application of the new criterion versus application of the Weather criterion for an existing RO-RO ferry. A significant advantage of the current method is that it can produce rationally the maximum wave slope for dynamic stability in a beam-sea environment (Fig. 2). Furthermore, the relation between critical wave slope and wind excitation has been set under investigation, given that even a small amount of bias can significantly lower the critical wave slope, combined with the fact that these ships are characterised by large windage areas.

c) Preliminary investigation on the use of the "engineering integrity" concept for design optimisation: We have taken as a basis a simple parameterised family of ship-like hull forms whose offsets are determined with the formula $y = \pm X(x)\, Z(x,z)$. $X(\bar{x}) = \frac{B}{2}\left(1 + a_2 \bar{x}^2 + a_3 |\bar{x}|^3 + a_4 \bar{x}^4\right)$ and

$Z(\bar{x},\bar{z}) = (1+\bar{z})^{n(\bar{x})}$ with the nondimensional longitudinal and vertical positions $\bar{x} = \frac{x}{L_{BP}/2}$, $\bar{z} = \frac{z}{D}$ and the superscript $n(\bar{x}) = s + t\,|\bar{x}|$ where s, t are free parameters [7-8]. For a finite set of hulls taken from this family we determine the hull restoring and the damping and then, through dynamic analysis, the critical wave slope for capsize. The effect of bilge-keels on the critical wave-slope is also examined. Eventually, the hull-form with the best stability characteristics is identified.

References

[1] THOMPSON, J.M.T. 1997 Designing against capsize in beam seas: Recent advances and new insights. *Applied Mechanics Reviews*, 50, 307-325.

[2] FALZARANO, J., TROESCH, A.W. & SHAW, S.W. 1992 Application of global methods for analyzing dynamical systems to ship rolling and capsizing. *International Journal of Bifurcation and Chaos*, 2, 101-116.

[3] HSIEH, S.R., TROESCH, A.W. & SHAW, S.W. 1994 A nonlinear probabilistic method for predicting vessel capsizing in random beam seas. *Proceedings of the Royal Society*, A446, 1-17.

[4] SPYROU, K.J. & THOMPSON, J.M.T. (eds.) 2000: *The Nonlinear Dynamics of Ships*. Theme Issue of the Philosophical Transactions of the Royal Society, A358, Mathematical, Physical and Engineering Sciences, Published by The Royal Society of London, ISSN 1364-503X.

[5] IMO (1995) Code on Intact Stability for All Types of Ships Covered by IMO Instruments. Resolution A.749(18), London.

[6] PAPAGIANNOPOULOS, S. *Investigations of ship capsize in beam seas based on nonlinear dynamics theory*, Diploma Thesis, National Technical University of Athens, September 2001.

[7] SAKKAS, D. *Design optimization for maximising dynamic stability in beam seas*, Diploma Thesis, National Technical University of Athens, September 2001.

[8] MIN, K.S. & KANG, S.H. 1998 Systematic study on the hull form design and resistance prediction of displacement-type super-high-speed ships, *Journal of Marine Science and Technology*, 3, 63-75.

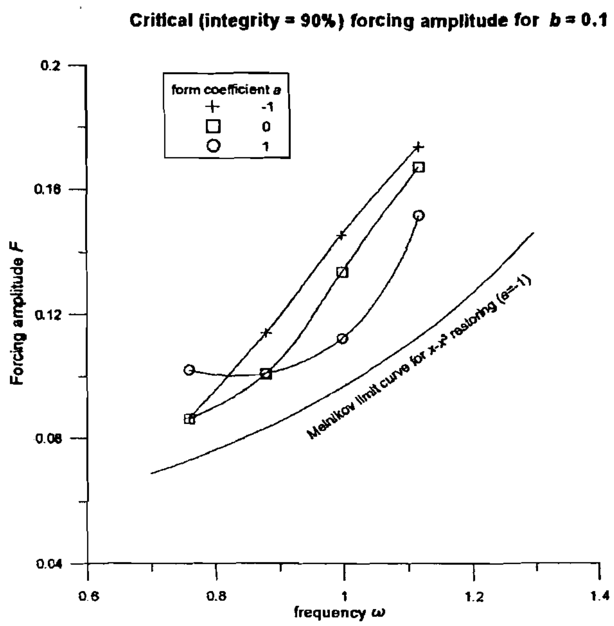

Fig. 1: 90% integrity curves for different types of restoring RO.

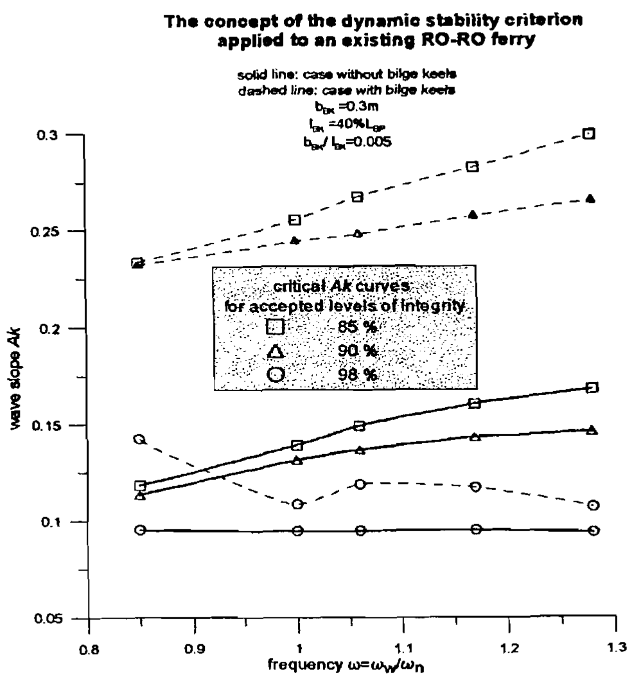

Fig. 2: The new criterion applied to an existing RO-