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On the Mathematical Modelling of Roll Motion of a Ship with a List

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ABSTRACT

The roll motion in beam waves of a RoRo with a list exhibits a dependence of the roll amplitude on the static bias angle. In this paper the problem is examined to find an explanation in terms of mathematical modelling of roll motion. It results that coupling and other effects usually claimed to be relevant in this context are of minor importance, while the observed difference in peak amplitudes is to be ascribed to a dependence of the damping and sometimes of the effective wave slope coefficient on the bias angle.

INTRODUCTION

Roll motion is with no doubt one of the most important and dangerous effects of waves on ships. The case of a ship that, in the presence of a regular forcing term, has lost the equilibrium of her upright position, and hence is in critical condition, has attracted the attention of researchers dealing with nonlinear dynamics due to the inherent peculiarities of the unsymmetrical oscillation. On the other hand, the regulatory aspects connected with the behaviour after damage call attention to the need of avoiding excessive list, as it delays or makes impossible the rescue operations and anticipates progressive flooding.

This paper discusses the problem of the correct mathematical modelling of roll motion in terms of a concentrated parameters approach (Ordinary Differential Equations) in the time domain. The starting point has been a set of experiments conducted in the Towing Tank of the University of Trieste on a scale model of a RoRo ship. The experiments have been performed in a regular beam sea at zero forward speed with the model partially restrained by means of soft elastic ropes to cancel the slow mean drift. At the same time this particular setup lets the model undergo roll, sway and heave motions. What this restraining can induce on the motion characteristics is still under discussion since in principle both the hydrodynamics (damping and excitation, …) and the dynamics (encounter frequency, …) of the phenomenon are altered with a strong dependence on the hull shape, displacement and relative wave height. In this context, a previous set of experiments on a similar RoRo vessel had been arranged so that the model was left free to drift under the action of waves. The order of magnitude of the mean drift was 0.01 m/s with the wave period ranging from 0.8 to 1.8 s and with a maximum wave steepness of $s_w = 1/20$. No appreciable differences in the peak period and in the peak amplitude of the roll motion were observed when comparing these results with those from the same experiments conducted with the model restrained. Obviously this conclusion cannot be general, but within the used ship typology and with a moderate sea state it can be argued that in our experiments the effect of the mean drift can be neglected.

In the present study 2 different loading conditions, several wave steepnesses and 2 characteristic heel angles obtained by static weight shifting (both on the windward and leeward side) have been considered together with the upright condition. The results indicate that the differences of the roll amplitude (measured from the mean value) and the mean value itself are not negligible, but the overall behaviour is characterised by moderate roll amplitudes only, in spite of the quite severe waves considered. This entails that the roll damping nonlinearity is expected to play a greater role than the righting arm one, with the notable exception of the effect of asymmetry introduced in the latter by the static heel.

The search of a suitable mathematical model has started from the above results and from the need to provide a simulation tool able to distinguish the different heeling directions with respect to the waves. This is not an easy task, which could not be solved by previous approaches (Contento et al., 1997) based on the use of a high efficiency parameter estimation technique. The reasons for this failure probably have to be found in the extreme sensitivity of the best-fit algorithm to the modelling of the restoring moment; this was represented by different polynomials, obtained by separately fitting the results of hydrostatic calculations to take into account the residual righting arm after transversal weight transfer. Only the symmetric case was completely solved (Francescutto et al., 1998), indicating quite a strong difference between the 2 loading conditions. In this paper, the problem is approached again, by using a different modelling of the righting arm and a basic robust identification technique based on a limited number of experimental points. The attention was indeed shifted to the peak values of the response amplitude curves to evaluate the damping contributions and to values out of resonance to calibrate the excitation intensity, here assumed as frequency-independent.

The results allow some preliminary conclusions on the relative importance of the various factors, i.e. damping, restoring, excitation and coupling of roll with other motions, suspected to be the origin of differences of the roll amplitude in the presence of bias.

EXPERIMENTAL RESULTS

A large set of experiments on the scale model (1:50) of a RoRo in regular beam waves (coming from starboard) has been conduct-

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