On the Roll Motion of a Ship with Partially Filled Unbaffled and Baffled Tanks — Part 1: Mathematical Model and Experimental Setup

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ABSTRACT

The work presented in this paper deals with the analysis of the roll motion of ships with free surface liquids on board. A mathematical model for the evaluation of the ship rolling motion is developed. It is based on the matching of the standard uncoupled roll motion equation with the Reynolds Averaged Navier-Stokes equations for the simulation of liquid sloshing inside the partially filled tank. Some discussions are reported on the problems which can arise when the above matching is performed. In order to validate numerical results, an experimental analysis is planned, considering the scale model of a fishing vessel equipped with a rectangular tank partially filled with water. The results obtained by the numerical runs and experimental tests are shown in Part 2 of the present work.

INTRODUCTION

As concerns maritime transportation, one of the challenges of the near future is constituted by the improvement in RO-RO safety. This is indeed essential also for the survival of this ship concept.

After the last accident, the sinking of Estonia, panels have been formed in the frame of SNAME (Hutchison, 1995) and IMO (IMO News, 1995) to study the problem. Several international and national projects which concern RO-RO safety are currently running (Svensen, 1995; Vassalos, 1995; Shimizu et al., 1995). Nobody has concluded that this ship concept has to be abandoned. Everybody agreed that water accumulation and motion on the garage deck play a relevant role, so that ad interim and long-term solutions have to be individualized and applied as new regulations. We can in particular quote the following: "Future research … analytical research to extend the earlier SNAME Ad Hoc RO-RO Safety Panel studies to include: a) vessel heave and roll motion; water sloshing on the RO-RO deck..." (Hutchison, 1995).

Water accumulation and sloshing constitute also a major problem as regards the safety of fishing vessels, while sloshing itself is relevant to structural calculations in tankers and in general in the transportation industry (Garside et al., 1992).

This paper is devoted to the analysis of coupled rolling/sloshing motions of a ship at sea. It reports the partial results of a long-term research undertaken at the University of Trieste (Armenio et al., 1995a).

The problem as a whole can be split into two different subproblems. The former regards the proper simulation of large amplitude motions of the ship, comprehensive of the coupling between the roll, sway and heave motion; the latter is related to the appropriate evaluation of large amplitude liquid sloshing inside the partially filled tank.

In the past, several mathematical models were proposed for the solution of such a problem. As a general rule, the problem was considered two-dimensional and linear ship motion computer codes have been matched to algorithms which solve the partial differential equations for the liquid sloshing.

As far as ship motions are concerned, the coupled heave, sway and roll motions' ordinary equations are solved with hydrodynamic coefficients calculated by means of the linear potential theory.

Several approaches have been outlined for the evaluation of the sloshing-induced loads. In the analytical approach of Rakhmanin et al. (1994), derived by the general theory of Moyseev in the hypothesis of inviscid liquids, the physical system has been regarded as an infinite degrees of freedom one. The inclusion of the first two sloshing modes in the solution proved to be an effective approach when the liquid depth inside the tank is large enough and in the range of large periods of excitation.

As regards the evaluation of the sloshing of water on deck of fishing vessels Dillingham (1981) solved the shallow water equations using more powerful techniques than RCM. At the same time Francescutto et al. (1994) have solved the nonlinear internal problem by means of a BEM technique in the hypothesis of inviscid liquid. Such approaches have provided good results as compared to experimental data for un baffled tanks, in a wide range of frequencies of excitation.

As regards isolated sloshing in a tank, several methods of increasing accuracy were developed in the past. The general case of liquid sloshing in a tank in a roll or sway forced motion was