International Journal of Offshore and Polar Engineering
Vol. 9, No. 2, June 1999 (ISSN 1053-5381)

An Investigation on the Applicability of Simplified Mathematical Models to the Roll-Sloshing Problem

Alberto Francescutto* and Giorgio Contento
Department of Naval Architecture, Ocean and Environmental Engineering, University of Trieste, Trieste, Italy

ABSTRACT

In this paper, the possibility of obtaining a simple and efficient description of the roll motion of a ship with liquids with free surface on board is discussed in detail. Available mathematical models with concentrated parameters are implemented and compared with scale model experiments. Critical points are evidenced by using a high-efficiency Parameter Identification Technique. Finally a model with good simulation capability is presented. It is based on a simple roll-sloshing coupling where the effect of the other motions is implicitly accounted for in the estimated parameters. The proposed mathematical model fits well the experimental data requiring the estimation of a reduced set of parameters, most of which can even be roughly assumed in the preliminary stages. The method appears of great interest in the sense of simulation capability of the dynamic effects of liquids on board during ship operations and in the frame of current research on damaged ship behaviour.

INTRODUCTION

Since the early papers of Chadwick and Klotter (1955), Van der Bosch and Vugts (1966), Van der Bosch and Zwaan (1970) and even earlier with the work of Watts (1883, 1885), the attempt to derive an appropriate mathematical model for the solution of the problem of a ship rolling with a partially filled tank on board has been attracting many researchers in the field of naval architecture. This is still a task for today especially as regards the modelling of water inflow/outflow after damage. In aeronautical engineering the problem of the route stability of missiles and aircrafts with a free surface tank was also considered of primary importance (Abramson, 1966). In the work of Van der Bosch et al. (1966) the main idea was to modify the traditional roll motion equation by simply adding the sloshing moment in the RHS of the equation as an additional exciting moment. The latter had to be evaluated experimentally from measurements on an isolated tank forced in a sinusoidal motion. By this approach the inherent complexity of developing a suitable mathematical modelling of the liquid motion in the tank could be avoided at the cost of large campaigns of experimental measurements. Later on Goodrich (1968) suggested a simple mathematical model constituted of two linear differential equations representing the roll angle and the slope relative to the ship of the free surface of the liquid (assumed flat) in the tank. There, the properties of the liquid in the tank were summarised by the natural frequency (derived from the linear wave theory), by a damping coefficient and by the classical static free surface correction factor. The excessive overlooking of the hydrodynamic aspects of the liquid motion in the adopted models pushed towards the searching of more realistic linear and nonlinear models (Faltinsen, 1974) including CFD-based approaches (Faltinsen, 1978; Mikelis et al., 1984; Pantazopoulos, 1992; Francescutto and Contento, 1994; Armenio et al., 1996a,b). More recently the occurrence of dramatic casualties at sea due to the flooding of the vehicle deck in RoRo ferries (Herald of Free Enterprise, Estonia) and the appearance of new typologies of tankers (double hull) and bulk-carriers affected by structural failures in the upper corners of the holds due to impulsive loads from cargo sloshing and by bulkhead failure due to flooding after damage, respectively, has given a new impulse to the research, both for a deeper understanding of the phenomena and for a rational approach to new rules. While the structural aspects are related more to a good prediction of liquid pressures and consequently to a detailed description of the fluid flow in the tank, the prediction of ship rolling amplitude for safety against capsize and sinking can be related to more simplified liquid models, since only the basic oscillation modes are primarily involved. From this perspective, simplified mathematical models for the roll/sloshing coupled motions are welcome by the ship safety community.

In this paper a consistent method (in the sense of the hydrodynamics involved in the sloshing problem) is developed and investigated. The equation for the sloshing motion is derived from the equivalent mechanical approach developed by Graham and Rodriguez (1952), where the rolling motion is considered to be described, for the time being, by a single nonlinear differential equation (Contento et al., 1996). As far as the latter assumption is concerned, i.e., neglecting the contribution of the sway and heave motion, the results of some previous studies on this problem without liquids on board (Roberts and Dacunha, 1985; Belenky, 1990; Hutchinson, 1991) drive us to the conclusion that whether or not sway motion is included in the model, the predicted roll amplitude doesn't change appreciably. However, sway motion can in principle be important in the presence of liquids on board. In this work an attempt is made to use a simple roll-sloshing model that, despite its relative simplicity, proves to be good enough to capture eigenfrequencies and possibly roll peak amplitudes. The mathematical predictions are compared with the experimental steady roll amplitudes of a large-scale model of a fishing vessel equipped with a flooded compartment with a constant amount of water and tested in a regular beam sea at zero forward speed. Four different liquid levels are analysed. A high-efficiency Parameter Identification Technique is then used to obtain the relevant parameters of the mathematical model (coefficients of the ODEs) and to discuss the model validity.

*ISOPE Member.

Received March 29, 1997: revised manuscript received by the editors April 2, 1999. The original version (prior to the final revised manuscript) was presented at the Seventh International Offshore and Polar Engineering Conference (ISOPE-97), Honolulu, USA, May 25-30, 1997.
KEY WORDS: Sloshing, ship rolling, ship stability.