Coupling between Ship Motion and Sloshing Using Potential Flow Analysis and Rapid Sloshing Model

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ABSTRACT
The coupled motion of a rigid barge with a partially filled tank is studied with a pulsating Green’s function approach, Rankine source method and a Rapid Sloshing Model (RSM). The aim of this paper is the comparison of the suitability of potential flow based methods and RSM, based on RANS, in simulating the fundamental physical aspects of liquid sloshing and their application to the coupling between sloshing and ship motion. The hydrodynamic forces and moments associated with the liquid sloshing are represented by relevant added mass coefficients. Subsequently, the coupled equations of motion of ship-partially filled tank in regular beam waves are solved.

Comparison of hydrodynamic characteristics of liquid sloshing (e.g. added mass) and ship motions obtained using the aforementioned methods indicate good overall agreement with other available numerical predictions and experimental measurements. All the methods used here capture well the physical aspects of the effects of sloshing liquid on ship motions.

KEY WORDS: Sloshing; sloshing-seakeeping coupling; CFD; Rapid Sloshing Model.

INTRODUCTION
The significant increase in demand for Liquefied Natural Gas (LNG) and the economic aspects of its transportation has resulted in an increase of the number and size of LNG carriers. One of the principal design issues for LNG carriers is sloshing because containment systems widely used nowadays have no internal structures to damp the liquid motion. Furthermore, because the weights of ship and cargo are comparable, the coupling effect between ship motions and sloshing requires further investigation. Considerable increases in the capacity of LNG carriers have renewed interest in the assessment of sloshing loads and the analysis of floating liquefaction and re-gasification units (floating LNG) requires the inclusion of the sloshing dynamics in a seakeeping model. Finally, recent incidents of sloshing damage onboard LNG carriers (Hine, 2008) have added further urgency to the improvement of sloshing analysis in LNG carriers and floating LNG design.

The work of Abramson (1966) summarizes the methods available in modern sloshing analysis, and Ibrahim (2005) gives an up-to-date survey of analytical and computational sloshing modeling techniques.

- Experimentation is used by classification societies, among them Det Norske Veritas, Lloyd's Register and the American Bureau of Shipping (2004). The model size is typically between 1/70th to 1/25\textsuperscript{th} of full scale, but the correct scaling of the model sloshing loads is often difficult (Abramson, 1966). Bunnik and Huijsmans (2007) carried out an experimental campaign at 1/10\textsuperscript{th} scale to assess scale effects.

- A number of theoretical fluid dynamics models with a wide range of complexity have been developed. A linear model for the aerospace industry was given by Graham and Rodriguez (1952). Faltinsen (1974) developed a third-order theoretical sloshing model. The restriction imposed by complicated tank shapes has been overcome using boundary element methods. An important advantage of theoretical models is that they provide a solution quickly. This makes them suitable for the study of sloshing-seakeeping interaction (Malenica et al, 2003 and Lee et al, 2008).

- A more general modeling technique is the numerical solution of the Reynolds Averaged Navier-Stokes (RANS) equations in Computational Fluid Dynamics (CFD). Some recent examples of CFD sloshing simulation include Hadzic et al. (2001) and Aliabadi et al. (2003). CFD can deal with violent sloshing beyond the limitations of theoretical models, but its application is restricted by considerable computational costs.

This study investigates the coupling between sloshing in a partially-filled rectangular tank and the seakeeping characteristics of a rectangular barge, carrying the rectangular tank on deck, stationary in beam regular waves. This topic is not a new one, but recently increased computational capability and strong interest from industry enabled systematic analysis both in frequency and time domain, as well as experiments. Rognebakke & Faltinsen (2001) carried out analysis and experimentation for two-dimensional problems. Kim (2001, 2002) and Nam et al (2006) investigated the three-dimensional problem in the time domain. The three-dimensional problem was investigated by Malenica et al (2003) and Newman (2005) in the frequency domain. Molin et al (2002) and Nasar et al (2008) carried out experiments on a