

Large-scale LNG Sloshing Model Tests

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The motion of the LNG fluid inside gas carriers is normally restricted by the loading condition of the vessel, i.e. the vessel is operated at either near empty condition or at fully loaded condition. In this way, the resonance or sloshing effects of the fluid on the ship's hull are limited. However, nowadays the LNG carriers are considered to be operating at intermediate loading conditions as well. Subsequently they will be sailing with partially filled LNG tanks. In this condition the LNG fluid is more likely to be induced into resonance due to wave action and roll motions. This resonance or sloshing behavior of the LNG fluid will lead to high-impact pressures on the thermally insulated ship's hull. Due to the different physical properties of the LNG fluid with respect to water in terms of density and viscosity, little is known of the behavior of the LNG fluid in resonance condition. Day-to-day practice in retrieving sloshing loading data is based on relatively small-scale model tests, e.g. 1:20 or 1:30. A disadvantage here is that, because any air pressure effects are not modeled, hydroelastic phenomena cannot be modeled at this scale. A way around this is to reduce the ambient air pressure when running scaled model tests. This by itself is not trivial to do. In this paper, however, we will describe a study of model test experiments on a large-scale 2-dimensional section (scale 1:10) of an LNG carrier in various loading conditions without depressurization. Using high-speed video observations the wave front formed by the bore of the LNG in resonance is related to measured impacts on the tank hull. Also measured is loading on a hydroelastic panel as part of the hull, with the correctly scaled structural properties. Significant influence of the stiffness on the pressure pulse was observed.

INTRODUCTION

Sloshing is a phenomenon of great engineering importance in the fields of naval architecture, ocean engineering and civil engineering. Severe sloshing can occur in a large oil storage tank, a reservoir and a fuel tank. Especially, an excessive sloshing motion in an LNG tanker can rupture the pipeline in a tank and the tank itself. The results of several research programs to investigate sloshing in Liquid Natural Gas (LNG) carriers are presented in Abramson et al. (1974). In the study, the history of sloshing-related problems in LNG carriers is discussed, including a list of recorded tank damages for LNG sloshing when the filling height is low and high relative to the tank length. In both cases, impact loads occur and induce extremely high pressures. Classification societies, containment system designers and ship operators have conducted thorough studies of these damages. In every instance the sloshing of the cargo was identified as the cause of the damage (Shin et al., 2003). Simple but effective plans were proposed to counter the sloshing impact in the fully loaded condition: The height of the chamfer at the topside was increased and the insulation box at the tank top was reinforced to withstand the sloshing impact.

There is a considerable number of investigations on the sloshing problem, both numerically as well as experimentally, the early ones from Chester (1968) and Chester and Bones (1968). For the case of small-amplitude excited motions, Faltinsen (2002),

Huijsmans et al. (2004) and Yamamoto et al. (1995) showed results of oscillation experiments where the computed impact pressures were compared with measured results.

A very steep wave front such as a hydraulic jump has been observed in experiments. The bore traveled back and forth between the tank walls (Hill, 2003). Many applications are given to the 2-D sloshing problem while nowadays 3-D geometries can be modeled as well. The violent sloshing problem is determined through a highly nonlinear free-surface motion. In these gravity-driven flows, viscosity effects generally play a minor role, but in the case of liquid LNG, the fluid properties are not so clear. The top layer of the LNG fluid consists of liquid LNG with a rich content of gas bubbles. So the density viscosity and vapour pressure may play a vital role. The presence of bubbles makes the potential flow-type of modeling inadequate. To overcome these kinds of deficiencies of potential flow solvers, volume of fluid (VOF) solvers are used nowadays (Wemmenhove, 2005). The LNG tank in this study is a closed tank top. In this paper the main results presented deal with the measurement of the impact pressures and wave heights due to a rolling motion of the tank from experiments at model scale. Besides the VOF method, Smooth Particle Hydrodynamics (SPH) are applied as well (Nam and Kim, 2006). Hydroelastic effects on cargo tanks have been studied by Lee et al. (1999) and Xiong et al. (2006). When the waves are overturning and hitting the water surface, air bubbles may be present in the fluid. In this case, a direct numerical solution based on potential flow with the nonlinear free surface conditions would break down.

Wemmenhove (2007) is working on an extension of the VOF method for a second (air) phase, including compressibility. The test results are being used to validate this method.

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