ABSTRACT

This paper presents an investigation of the influence of raised invar edges on tank sloshing under partial-fill conditions. Through multiple scale wedge drop tests and 2-D sloshing model tests, the authors were able to show that raised invar edges tend to enhance the magnitude of sloshing pressures. The enhancement effects were found to be highly localized and vary with the size of loaded area. The findings from this work emphasize the importance of considering the physics of invar edge effects in defining the design pressure to be used in assessing the integrity of membrane LNG tanks.

KEY WORDS: LNG carrier; Membrane containment system; Raised invar edges; Liquid sloshing

INTRODUCTION

Safe design of Membrane Insulation Systems (MISs) in LNG ships requires adequate assessment of sloshing loads and structural capacities. Dynamics of the MIS structural designs require that sloshing pressures be defined with fine spatial and temporal resolution on the order of 0.1 square meters and 10^-4 seconds, respectively. The requirement of fine spatial and temporal resolution has posed significant challenges to analytically based methodologies for prediction of sloshing impact pressures. In the past, researchers have conducted model-scale sloshing tests in order to define prototype design pressures for structural integrity assessment (Bass et al. 1980), although using tanks with smooth walls. However, at prototype scale, the two widely-used MIS systems both have raised elements, corrugations in the case of MKIII and raised invar edges in the case of No.96. The MKIII primary membrane includes a square pattern of corrugation cells formed by the crossing rows of larger and smaller corrugations, both with spacings of roughly 340 mm. In the case of No.96 system, parallel rows of raised invar edges are present with spacings of roughly 500 mm and contain the weld used to join the sheets invar that make up the primary membrane. Recently ExxonMobil has developed sloshing assessment methodologies (Sandström et al. 2007, Kuo et al. 2009) using corrugated tanks for assessing integrity of the membrane LNG containment systems.

There have been some studies performed to understand the influence of corrugations on sloshing pressure. Due to the complexity of sloshing model tests, researchers have often used the well-defined wedge entry problem as a means of understanding the basic effect of corrugation. Wedge drop tests have been widely used in the industry as a means to investigate fluid impact problems, partly due to the existence of analytical and numerical solutions for the wedge entry problem. Wagner (Wagner, 1932) first developed a two-dimensional theory to study vertical entry of a wedge and to calculate the local impact pressures. Wagner’s solution is only applicable when the dead rise angle of the wedge (the angle between the wedge surface and the water surface) is not small and when air trapped between the wedge and the water surface is negligible.

Chuang (Chuang, 1967) carried out a series of experiments to study the effects of dead rise angle on a rigid wedge slamming in water. Based on measurement and high-speed underwater video, he reported that air was trapped between the impact wedge surface and the water surface for very small dead rise angles (less than 3 degrees). Such trapped air provided cushioning during the impact, resulting in lower measured impact pressures. For a wedge with a dead rise angle of 3 degrees and larger, most of the air had escaped at the instant of impact.