Marine Structures 56 (2017) 99–116

Contents lists available at ScienceDirect

Marine Structures

journal homepage: www.elsevier.com/locate/marstruc

Sloshing assessment of the LNG floating units with membrane type containment system where we are?☆

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ARTICLE INFO

Article history:
Received 9 September 2016
Received in revised form 21 November 2016
Accepted 7 July 2017

Keywords:
LNG
Cargo containment system
Sloshing
Seakeeping
Impacts
Hydro-structure interactions

ABSTRACT

The paper gives an overview of the current status of the methods and methodologies which are in use for the evaluation of the structural response induced by sloshing impacts. First the overall problem (seakeeping, sloshing, impacts, statistics…) is discussed and then the accent is put on the modeling of hydro-structure interactions which occur during the severe sloshing impacts in the tanks of the Liquefied Natural Gas (LNG) Carriers of membrane type. The main conclusion is that the sloshing assessment procedures are still under investigations and there are still no fully satisfactory methods and methodologies available to solve the problem fully consistently within the so called direct calculation approach. That is why, for the time being, a relatively simplified procedures are used in practice.

1. Introduction

Sloshing became a very important practical issue in the last decades due to the increased activities in the LNG transport. Large numbers of LNG ships were built or are under construction with the capacities which almost doubled as compared to the classical LNG ships (from 138 000 m^3 to 260 000 m^3). At the same time the projects of several LNG FPSO (Liquefied Natural Gas – Floating Production Storage Offloading) units, were built or are in the design process, among which the *Prelude* LNG FPSO operated by Shell is probably the most well-known. This FPSO represents the biggest floating unit in the world and its length is close to 500 m for breadth of 74 m and the total capacity is around 220 000 m^3 of LNG together with 90 000 m^3 of LPG and 120 000 m^3 of condensate. The most common LNG units belong to the so called membrane type which is of main concern here. Within the membrane type concept, the LNG is kept liquid at very low temperature (−165 °C) by complex cargo containment system (CCS) which is attached to the ship structure. There exist today two main types of CCS (NO96 and MARKIII) and they are shown in Fig. 1. Both systems are owned by Gaztransport and Technigaz (GTT), and both systems are structurally very complex and involve different types of materials (plywood, perlite, invar, stainless steel, foam, glue…) which are connected together and attached to the hull structure. For reference, the CCS which was used for *Prelude* LNG FPSO is the MARKIII CCS.

☆ Paper prepared in conjunction with the ISSC Committee work 2012–2015. Edited in cooperation with Professor Carlos Guedes Soares, Chairman of ISSC2015 Conference.

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http://dx.doi.org/10.1016/j.marstruc.2017.07.004
0951-8339/

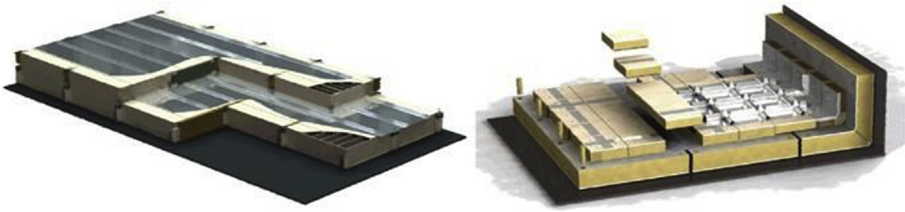

Fig. 1. Two major types of the cargo containment systems: left - NO96 and right - MarkIII.

In parallel to the increase in size of LNG vessels, the operational requirements became more and more severe. In the past, LNG ships were allowed to operate either in full or empty tank conditions, while today there is a necessity to allow for sailing at any partial filling for some LNGC such as LNGRV (Regasification Vessel), FSRU (Floating Storage and Regasification Unit) or LNG-FPSO. This requirement introduces serious difficulties in the design of both the cargo containment system and the associated ship structure. Indeed, depending on the filling level and on the operational conditions, violent sloshing motions may happen and the direct consequence is the occurrence of different impact situations which induce the extreme structural loadings and can be devastating for both the containment system and the ship structure. From modeling point of view, as far as the hull structure is concerned the situation is slightly simpler because most often only the global loads matters, while for the cargo containment system the situation is significantly more complex because the CCS is directly exposed to the impact loading.

Evaluation of the structural response of the cargo containment system is probably one of the most challenging problems in the field of hydro-structure interactions in seakeeping. Both the reliable deterministic models for local hydro-structure interactions, as well as the overall rational methodology for determination of the representative design conditions, are still missing. By taking quick look at the typical sloshing behavior (Fig. 2) we can easily understand why it is so.

One of the main issues, blocking the progress in this field, appears to be the lack of the reference results.

Indeed, and unlike the other hydro-structural problems in seakeeping, the small scale sloshing model tests do not provide the clear reference results especially in terms of the pressure measurements. This is due to the fact that it is impossible to ensure, at the same time, the proper scaling of all the different physical phenomena which are involved during the different impact situations (aeration, compressibility, condensation, hydroelasticity…). These complex physical phenomena are usually randomly combined so that, even for the same testing conditions, we can hardly ensure the repeatability of the results. For those reasons and in spite of the fact that very precise pressure sensors are employed, the statistical properties of the measured pressures show very unusual statistical behavior, as it will be discussed later. On the other hand the feedback from the full scale measurements is also limited and it is still not possible to accurately measure all the relevant physical parameters (sea state, free surface shape, fluid velocities, pressures, degree of aeration, structural response…). Finally, the numerical models do not seem to be accurate enough and this is not due only to the CPU time issues but also to severe numerical difficulties associated with the numerical modeling of the hydro-structure interactions which occur during sloshing impacts (important changes of the free surface geometry, flow separation, aeration and compressibility, hydroelasticity, condensation…). Due to all the mentioned difficulties and in spite of all the important research efforts worldwide, the design methods which are currently in use are still based on rather simplified comparative approaches, as it will be discussed later in the text.

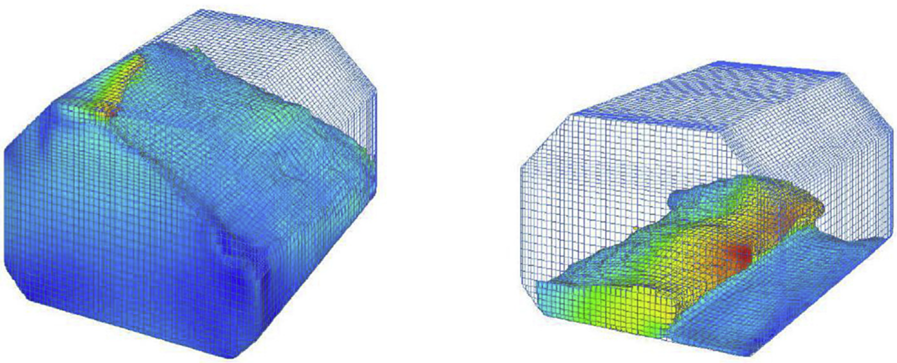

Fig. 2. Violent sloshing motions for different filling levels.