INTERACTION OF LIQUID MOTION ON MOBILE TANK STRUCTURE

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Abstract

Mobile tank are widely used for transport various goods not only liquids but also gases, material in bulks and even cryogenic liquids. Such tanks have to fulfil a number of requirements arising from operational as well as design aspects, they have to resist on high pressure load and extremely low temperatures in case of cryogenic tanks. Mobile tank used on railway, vehicles or as a container on ships have to fulfil requirements for dynamic load that arising from interaction of fluid at tank. A lot of standards defines requirements for various mobile tanks and defines design procedures. One of most difficult is the interaction between fluid and tank structure during tank operation. Available standard defines a lateral and longitudinal acceleration as a dynamic load that tank has to fulfil. Standards like ADR or EN defines a simplified method of evaluating strength of tank structure on dynamic load. This paper presents a method of evaluating interaction of sloshing liquid on tank structure using FSI (Fluid Structure Interaction) with the use of CFD and FEM tool. Ansys Workbench environment simulation was used to evaluate influence of liquid motion on tank structure. CFD allowed simulating liquid sloshing at the tank at simultaneous longitudinal and lateral short peak of acceleration. Than these results were applied to structural simulation, for checking tank structure strength under loading with sloshing liquid.

Keywords: *mobile tank, FSI simulation, liquid sloshing simulation*

1. Introduction

Mobile tanks are used from decades to transport various goods, from liquid to goods in bulk and even cryogenic liquid. They were a subject of a lot of research work what lead to provide adequate standards depending on tank assignment. All of them define design requirements and strength requirements that shall be fulfilled. For example standard [1] and [2] specified detailed requirement for various tank design but they have one common requirement: tank structure shall resist specified load defined by lateral, vertical or longitudinal acceleration. Both standards define this acceleration as 2g in vertical and longitudinal direction and 1g in lateral direction. Nowadays mobile tanks are subjected not only for one liquid but the whole family, which may vary in density and due to the limit in total weight it may happen that tank is not filled to its nominal capacity. In such cases tank has to be provided with swash plates to eliminate unfavourable dynamic load of sloshing liquid on tank structure. Therefore swashing plates as well as tank structure has to resist these dynamic loads arising from liquid motion. Standards define the load from sloshing liquid as an equivalent pressure that should acts on swash plates as well as tank walls. This is very conservative approach and sometimes do not allow to investigate phenomena caused by sloshing liquid in a correct way. Available on the market design and simulation tools offer a rich possibilities but investigation of influence of liquid in motion on tanks is not easy task. There are few various approach for simulation of such problem. One of them is FSI (Fluid Structure Simulation) which combine phenomena of liquid motion with consideration tank structure. It can be performed using two independent codes (CFD and FEA) or one that have possibilities to use Eulerian-Lagrangian approach [3]. Both of them have advantageous and disadvantageous. CAE systems supporting Eulerian-Lagrangrian elements avoid problems with exchanging data from fluid simulation to structure but offer less possibilities in flow simulation. Using independent CFD and FEA tools requires appropriate translators for exchanging data.

There are two types of FSI simulation: one way, when information from flow simulation is transferred into structure and two way simulation, where data are exchanged between both: fluid and structure. In this paper was presented using one way FSI simulation to investigate influence of liquid motion on typical, atmospheric tank on its structure. For this purpose Ansys Workbench environment was used.

2. Object of study

As an object of study was selected tank that is used to storage and transport liquids under atmospheric pressure like oil products, water, milk, etc. The tank is presented in Fig. 1. It consists of three chambers separated by swash plates with capacity ca. 26 m^3. The tank has ellipsoidal cross section (1200x900) and length 8000 [mm]. The tank is subjected for transport liquids under atmospheric pressure and can be assembled to the road vehicle underframe at the tank saddles. The thickness of tank shell as well as swash plate is 3 [mm]. Swash plates divide tank volume into three more or less equal parts and due to single filling and emptying system allow liquid flowing between chambers. According to standard recommendation the swash plate has a cross section of 75% of the tank.

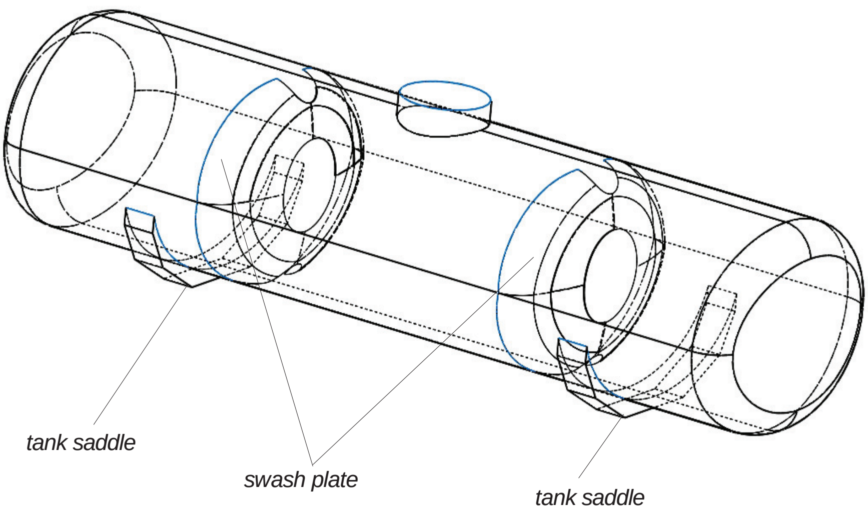

Fig. 1. Investigated model of tank

The tank has two saddles welded to the tank shell which are placed between swash plates and tank head.

3. FSI simulation of the tank

Investigation of influence of liquid motion on tank structure was performed by FSI simulation in Ansys Workbench simulation environment. Applied way use two independent CFD and FEA codes, therefore, two computational models of tank was prepared, one for CFD one for FEA. These models are presented in Fig. 2 and 3.

CFD model presented on Figure 2 was prepared by Ansys mesh tool and consist of hexahedral 3D cells. While FEA model presented in Fig. 3 was prepared using shell, quadrilateral shape element with 4 nodes. At both models an interface for transferring information between CFD and FEA codes was applied to the internal surface of tank and to both plates. As the deformation of tank shell have a minority influence on liquid motion one way FSI simulation was used in the way presenting in Fig. 4.

Fig. 2. CFD model of the tank, 3D hexahedral cells

Fig. 3. FEA model of the tank, quadrilateral shell elements

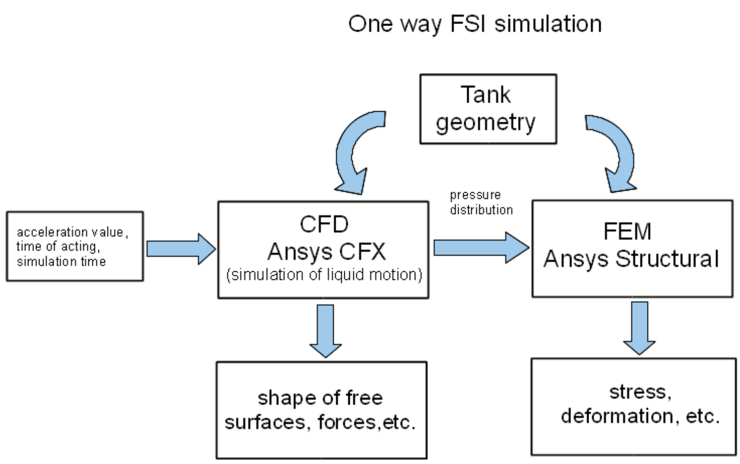

Fig. 4. One way FSI simulation of the tank

Flow simulation was conducted for the following conditions:

- liquid is water with properties at normal ambient temperature,
- tank is filled to half its nominal capacity,
- flow is two phase (water and air), homogenous with standard model of free surface,
- tank walls are ideal smooth,
- model is in thermal equilibrium, there is no heat exchange between fluids and environment,

- simulation is in transient conditions with acceleration peak of 2 g in longitudinal direction and 1g in lateral, duration of acceleration is 0.2 [s],
- flow is turbulent with RNG k-ε model,
- simulation time is 5 [s].

At the first stage CFD analysis was conducted in which is able to find shape of sloshing water at each stage of simulation, the peak pressure values appearing on tank walls, forces acting on tank shell, etc. As an example, below figure shows shape of water surface at time 0.3 [s].

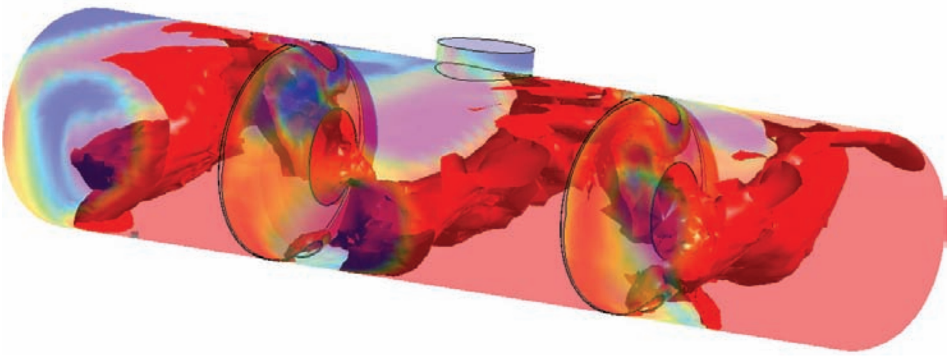

Fig. 5. Shape of water surface at time 0.3 [s]

At the next step the peak value of pressure caused by sloshing liquid was imported to FEA model of the tank. Fig. 6 shows pressure distribution imported from CFD simulation applied to tank shell and to the swash plates as well.

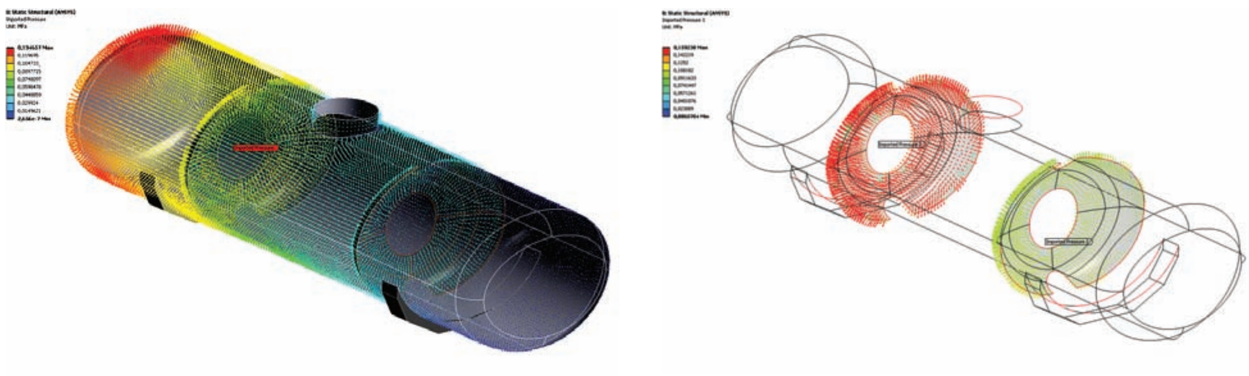

Fig. 6. FEA model, imported pressure

Defined in Ansys Workbench FSI simulation allows to import pressure value at defined interface between fluid and structure for any simulation time. In presented results was selected maximal values appearing during simulation. Below figures show selected results of FEA results, as an equivalent Von Mises stress and total displacement. This allows capturing maximal values of stresses and deformation that may appear during tank operation.

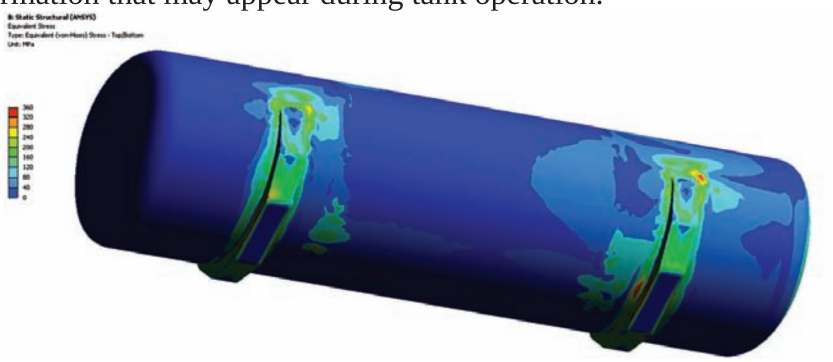

Fig. 7. FEA results, equivalent stress [N/mm²]

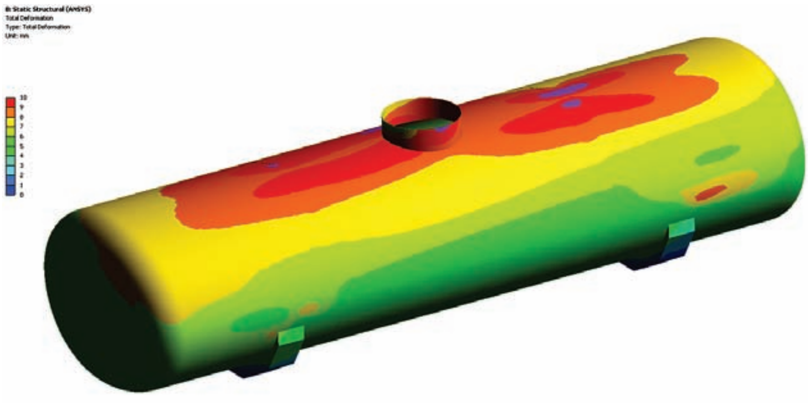

Fig. 8. FEA results, total displacement [mm]

Presented results shows maximal values of stress and deformation that appears on defined acceleration load. Investigation of these results allows finding the critical points of tank structure at any time of duration of liquid motion.

4. Summary

This paper presents FSI simulation of tank for transport oil products or other liquid under atmospheric pressure. Presented one way FSI simulation was conducted in Ansys Workbench simulation environment by using Ansys CFX and Ansys Structural codes. Prepared FSI model of tank allowed testing tank structure on dynamic load caused by liquid motion under inertial excitation of value 2g in longitudinal direction combined with lateral acceleration 1g. Defined simulation FSI model enable to obtain peak pressure values under defined excitation and check its influence on tank structure.

FSI simulation seems to be very efficient design tool for mobile tanks especially under dynamic load caused by liquid motion. It allows not only capturing maximal values of stresses and displacement but also estimating stress variations under changeable dynamic load (caused by sloshing liquid) which next might be used to assess fatigue strength. It also allows determining pressure changes depending on excitation conditions (acceleration value, direction, duration) and its influence on tank structure. Such simulations might not only be used for mobile tank but also for stationary tank when liquid motion has significant meaning. Such case appears for tanks which have to fulfil requirements for seismic load.

FSI allows to capture phenomena caused with liquid motion much wider for tanks used in road, railway and see transport systems to optimize tank structure.

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