INFLUENCE OF LIQUID SLOSHING ON ROAD TANKER DYNAMICS AND LOADING

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Summary This paper presents the analysis of the tank dynamic properties due to the liquid sloshing inside the road tanker reservoir. The effect of the relative liquid movement in the tank on the allowed normal tanker acceleration was investigated on the basis of the finite element simulation. The approach allows to optimize the baffle design in road tankers.

INTRODUCTION

During transportation the liquid oscillations of cargo in the partially filled tanks significantly reduce the longitudinal and lateral stability and control as well as increase the loads on the tank structure [1]. In order to reduce the loads the permeable and impermeable baffles are set in tanks. In some cases the breakwaters are additionally installed to reduce the risk of rollover and to restrict the fluid movement in the transverse direction [2].
Earlier for studying the dynamics of tanks with liquid only approximate methods have been applied. Baffles and other damping systems were examined only on the basis of quasi-static approach and experimental work [3]. So many problems of oscillations and stability of tanks as systems with solids and liquids have not been solved.
In the present paper some results of our studies of the road tanker dynamics are presented. They are associated with the use of the Navier-Stokes equations for solving fluid mechanics problems. The analytical solution of these equations has not been obtained yet. Therefore, to analyze the viscous liquid flow in tanks the numerical methods are being used.

RESULTS

To clarify the characteristics of flow in the tank, the case of motion with constant deceleration has been investigated. ANSYS and STAR-CD finite element analysis software packages have been used. It has been determined that during the tank 1 to 10 m/s^2 deceleration the maximum hydrodynamic pressure increases while the tank is being filled in with liquid cargo. The maximal pressure is observed at large decelerations and 90% of liquid-filling. The more deceleration increases the clearer extremum is.
The data analysis has shown that the pressure increases due to the appearance of the local compression of the liquid which originates in the transition region from spherical to cylindrical part of reservoir and then "runs" on the upper surface of the tank to the opposing bottom as shown in fig. 1. This fact causes disturbances of the boot lid-hatch close fitting and leads to a cargo loss and environmental pollution.

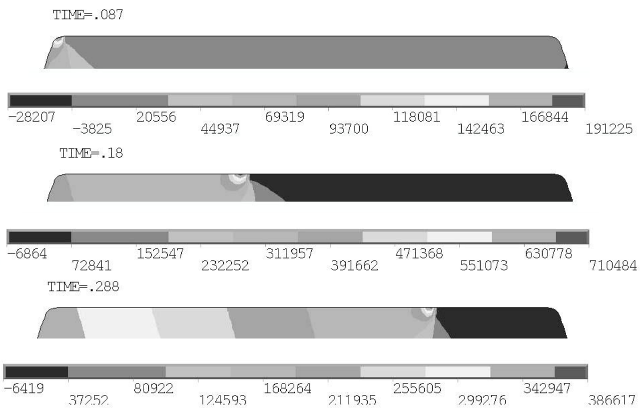

Fig. 1 – Fragments of the liquid pressure distribution diagrams (Pa) on the top of a cylindrical shell

At the quick entrance into the turn the liquid center of gravity moves to the side wall of the reservoir by moving the liquid inside the tank and causing the appearance of the relative motion inertia forces. The time spent on the entrance into the turn has a significant effect. When the turning is very fast the liquid oscillation amplitude may increase several times and during the second maneuver it can even exceed this value.
As a rule, only centrifugal inertial forces are taken into consideration when analyzing tank rollover. But inertia relative motion may significantly influence the stability during rollover. Graphs of acceptable acceleration normal component for

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MTM-59–tanker constructed without taken into account 1 and with taken into account 2 of the relative liquid motion depending on the mass filling of the tank are shown in fig. 2.
The graphs show that allowable normal acceleration decreases when the relative velocity of the fluid is taken into account. When the tank filling levels are 20–70 % the reduction reaches 25 %. Thus, the value of allowed normal acceleration and permitted speed on turns can't be obtained for practical purposes with acceptable accuracy without the relative movement of liquid taken into account.

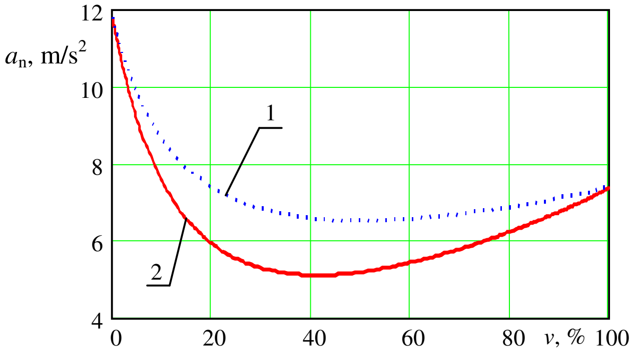

Fig. 2 – The dependence between the allowable normal acceleration a_n of the tanker and its filling level v

Despite the great diversity of damping liquid oscillations in the tanks there is a lack of techniques allowing to estimate the efficiency of various types of partitions and optimize their design. We propose a new method for evaluation of the baffles damping ability. It is based on the analysis of energy dissipation during the first period of liquid oscillations. At the very moment there appear large dynamic loads on structural elements or the overturning of a tanker may happen.
To analyze the sloshing of liquids we performed finite element modeling of fluid flow in the reservoir tank with 4 m length and 1.5 m height. A perforated baffle is installed in the middle of the tank (fig. 3). To describe the flow of fluid in the reservoir κ-ε turbulence model was put into practice. This model is based on the turbulent kinetic energy κ and turbulent energy dissipation rate ε equations. Rectangular finite elements with a regular partition of the liquid have been used. The final finite element model consists of 10,000 items.
The maximum oscillations damping takes place if the perforations have a diameter of 9 cm. (fig. 4). So the fluid effect on the tank dynamics will be less significant in comparison with other variants of partitions.

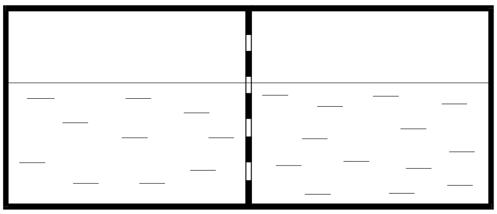

Fig. 3 – Scheme of baffle in tank reservoir

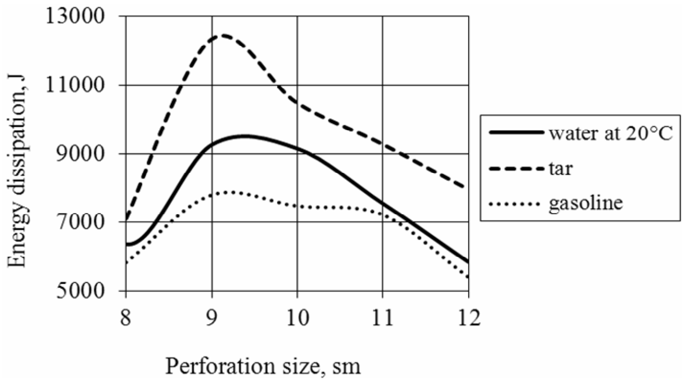

Fig. 4 – The dependence of fluid energy dissipation on perforation size

CONCLUSIONS

A similar analysis can be performed for tanks of various shapes with different partitions set schemes. Also various movement schemes of tankers can be examined and particular properties of different liquids can be taken into account. Such analysis is possible only at modeling liquid as a continuous medium.

References

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