DESIGN OPTIMIZATION OF PERFORATED BAFFLES INSTALLED IN THE ROAD TANKER RESERVOIR

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ABSTRACT. The present work develops the earlier suggested baffle optimization method based on the maximization of liquid energy dissipation. The 3D finite element modeling of the liquid sloshing into the reservoir has been carried out by means of the ANSYS CFX software package. The obtained law of the hydrodynamic pressure distribution in the reservoir was used for the stress analysis. Shape optimization of the perforated baffle was performed on the basis of genetic algorithm.

KEY WORDS: perforated baffle, liquid sloshing, stress-strain condition

1. Introduction

The main feature of liquid cargo transportation is the large amplitudes of the liquid center of mass oscillations which affect the controllability and stability of road tankers, especially if the reservoir is partially filled with liquid [1–3].

To prevent liquid sloshing in reservoirs of road tanks during transient motions the internal partitions are installed [4–9]. Earlier only approximate methods have been applied while studying the dynamics of tanks with liquid. Baffles and other damping systems were explored only on the basis of quasi-static approach and experimental investigations. So many problems of oscillations and stability of the tanks, as systems, including solids and liquids, have not been solved. However, the presence of varied partition designs used for the liquid sloshing damping [8], shows that the problem of optimizing the number and type of partitions hasn’t been solved yet.

We have previously developed a method for optimizing the damping devices based on the minimization of liquid energy dissipation during the first cycle of its oscillations [9, 10]. The purpose of the present work is to determine the shape and size of a rational transverse perforated partition placed in a cylindrical road reservoir on the basis of our method considering the limitation of the maximum allowable stresses in the reservoir construction.
2. Mathematical modeling of liquid flow

The processes occurring during oscillations of liquid with free surface were analyzed on the basis of solutions of nonlinear differential Navier-Stokes equations in partial derivatives:

$$\frac{d\bar{v}}{dt} = f - \frac{1}{\rho} \text{grad } p + \nu \Delta \bar{v},$$

$$\text{div } \bar{v} = 0.$$

where $\bar{v}$ – the velocity vector of the fluid particles, m/sec; $t$ – time, s; $f$ – distribution density of external body forces acting on the fluid particles, N/kg; $\rho$ – liquid density, kg/m$^3$; $p$ – liquid pressure in the considered point, Pa; $\nu$ – kinematical viscosity of liquid, m$^2$/sec; $\Delta$ – the Laplace operator.

To consider the flow turbulence $k$-$\varepsilon$ turbulence model was used. This model implementation involves the calculation of the turbulent kinetic energy $k$ and the turbulent energy dissipation rate $\varepsilon$ of each fluid finite element every time step [11, 12]. The above-mentioned turbulence model considers that when liquid begin to slosh the small eddies appear. They are continuously reshaped and disperse liquid kinetic energy.

3. Computer modeling of liquid sloshing in road reservoir

3.1. Computer model creation

The object of the investigations was a cylindrical reservoir of road tank with 4 m length and 2 m in diameter. The partition can be installed in the middle of the reservoir. Finite element modeling was performed in the ANSYS Workbench (CFX) environment. By defining the characteristics of liquid density and viscosity the liquid cargo in the reservoir was divided into air and liquid phases. It was assumed that a cylindrical wall was smooth. As the kinematic boundary condition the no-slip condition was used. The results of our previous investigations have shown that the 60 % filling level is the most unfavorable [9, 10] for stability and controllability of road tank, so the further analysis was carried out for this case.

3.2. Computational results

The computations of the liquid energy dissipation in the reservoir equipped with perforated baffle were done for the different perforation sizes. It was considered the case of the tank movement with a constant deceleration of 0.6 g and initial speed of 15 m/sec. It was assumed that initially the free surface is horizontal.

The performed computations of liquid energy dissipation for different variants of the perforations locations in the baffle have shown that the maximum liquid energy dissipation during its sloshing in the tank with the above-mentioned dimensions is achieved when the size of the perforations is 10–12 cm, and the area of the holes should not exceed 30-40 % of the baffle [10]. The values of water energy dissipation velocity and energy dissipation for perforated baffle are shown at Fig. 1.
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sure distribution in the most loaded points of reservoir with internal perforated baffle for the case of 11 cm perforation holes’ diameter is shown at Fig. 2.

Fig. 1. The dependences of the water energy dissipation velocity (a) and water energy dissipation (b) on time for the case of 11 cm perforation holes’ diameter

Fig. 2. Pressures located in a) the perforated partition; b) front reservoir wall (in the direction of movement)

3. Optimization of baffle shape

3.1. Optimization method

Road tanks operating experience shows that the joint places of the shell walls and the partition are the most stressed. After a certain operation period the cracks appear in these places, indicating exceeding of stress the limit fatigue values. Therefore, the partition has to provide both the maximal liquid damping and fulfillment of the stress conditions.

The above-mentioned results were taken as the basis for further analysis of the partition strength the action of hydrodynamic loads. For manufacturing convenience (from a technological point of view) partition must have the form of a rotation body (Fig. 3). The depth of the partition (which corresponds to position the point 9 in Fig. 4) is 100 mm in order to ensure its strength. So the problem to solve is to determine the coordinates $x_k$ ($k = 1 \ldots 8$) of such points 1-8 that $y_{k-1} - y_k = \text{const}$.

As for the solving method of perforated baffle shape optimization problem the basic form of genetic algorithm proposed by J. Holland [12-14] was applied. The data of this problem has to be performed as individual genes. The
basic gene array consisted of baffle points (Fig. 4) selected from all over the range \((0 \leq x_i \leq 100\ \text{mm})\). In order to determine the coordinates of points with 1 mm accuracy there were considered \(2^7 = 128\) possible positions, calculated with a constant pitch.

![Fig. 3. Model of perforated baffle installed inside the reservoir](image)

Then, from the gene sets the chromosomes which determine baffle shape were created. The points 0...9 were connected with a smooth curve using cubic splines. The shell was formed by rotating the curve about the \(x\)-axis. Then, the computations of the stress–strain state of the loaded baffle with each set of points were performed. Baffle loading consisted of hydrodynamic loads, which were determined by the pressures in the tank with a perforated baffle of 11 cm perforation hole’s diameter.

The dependence of the maximum stresses in the structure on the \(x_i\) points position was considered as the objective function to be minimized. In accordance with the algorithm described in [13, 14], the selected genes had to satisfy the objective function the best way. Thus, the computations included 30 iterations with \(2^{26}\) number of possible solutions and allowed to obtain the required shape of internal perforated baffle.

### 3.2 Computational results

The obtained results shown that the lowest stresses were distributed in the
perforated partition of convex shape at time 0.05 sec as shown at Fig. 5. Its feature is sufficiently large curvature radius of the central part and a much smaller one in the place of partition connection with the reservoir body. The obtained values of equivalent stresses don’t exceed the yield strength of structural steel, so that structural strength conditions for the perforated baffle are performed.

4. Conclusions

1. It was suggested the method of optimal baffle shape determination based on two criterions: maximal liquid energy dissipation and minimal stress distribution in the baffle and reservoir.

2. On the basis of the genetic algorithm it was found the optimal form of internal perforated baffle which provides minimal stresses in the structure.

3. The developed method of analysis can be used for optimizing of the shape of the partitions installed inside the tanks of other shapes and sizes.

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