FEATURES OF FLOWVISION AND ANSYS SOFTWARE'S COMBINED USE FOR THE DETERMINATION OF STRESS CONDITIONS IN OIL TANKS[1]

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During operation of vertical cylindrical tanks for storage of oil and oil products significant quantities of compacted sediments can be formed and accumulated. As a result, tank useful capacity, tank farm turnover are reduced, oil storage cost is increased due to the necessity to put tanks out of operation and perform their cleaning. There are methods of cost reduction in case of timely removal of forming sediments by using, for example, various screw-type devices.

In order to determine deformed condition of the tanks during washout and mixing of sediments with movable oil jet produced by operation of the screw-type devices, FLOWVISION and ANSYS software systems were applied. The article describes some features of solving the task.

PROBLEM DESCRIPTION AND TASK SETTING

It is known that steel vertical cylindrical tanks are used for storage of oil and its refined products. During operation significant quantities of sediments consisting mostly of paraffin can be formed and accumulated on the tank bottoms [1]. As a result, tank useful capacity, tank farm turnover are reduced, oil storage cost is increased due to the necessity to put tanks out of operation and perform their cleaning.

At present, in order to fight bottom sediments on bottoms of steel vertical oil tanks, sediment prevention and washout devices are used – washout heads, "Diogen", "Typhoon" devices, etc. They are designed to wash out and mix sediments with movable oil jet in tanks of various capacities.

Operation of these devices ensures quick washout of bottom sediments. Design of the device is intended for use in liquids with viscosity to 40 centistokes. Using a propeller, the device produces oriented submerged liquid jet moving cyclically over the tank bottom by means of automatic rotation drive. The jet mixes heavy paraffin sediments and mechanical impurities, which are suspended in total oil mass and then removed by oil pumping out of the tank.

For substantiated conclusions on possibility of safe operation of the above devices, the task of studying the tank structure behavior at dynamic loads, which occur during washout and are caused by jet streams, has been set. Such task cannot be solved

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by applying only analytical methods or combination of known solutions. It is explained by complicated description of the mixing device operation [1] as well as by the fact that the stream emerging in the tank is a two-phase stream with physical properties (density and viscosity) changing not only on time basis, but also on space basis.

ANALYZING WAYS OF SOLVING THE TASK AND SUBSTANTIATION OF COMPREHENSIVE APPROACH

Taking into account peculiarities of the task setting, an attempt to reach the solution was made using modern software systems, which implement numerical calculation methods, for both modeling the stress condition of the tank structure and obtaining the stream characteristics, which determine loads on the tank bottom and walls.

It should be noted that attempts to solve the above task using numerical modeling were already made [2]. In this work, capabilities of ANSYS engineering analysis software combined with its included FLOTRAN module were used to reach the solution. Stream and loads in the tank during operation of the washout head of the ejecting type device as well as the resulting stress condition of the structure were modeled.

The positive point of the obtained approach should be considered to be application of ANSYS software system, which proved to be good in solving similar tasks, for determination of the tank stress condition. The drawback of the method of solving the task as a whole proposed in work [2] should be considered to be limited capabilities of FLOTRAN module for modeling complicated hydrodynamic processes, and, as a result, loads on the tank walls. The problem is that in FLOTRAN module it is impossible to model operation of devices different from the type considered. In practice, devices where the working element is a screw (for example, “Diogen” and “Typhoon” devices) are frequently used. Another considerable drawback is that in case of the partially filled tank FLOTRAN module does not allow to model wave-forming process at the oil-air boundary which is necessarily initiated by the device itself, and the less the filling height is, the more intensive the wave-forming process is. Moreover, FLOTRAN is not capable of accounting for considerably different physical properties (density and viscosity) of oil and sediment which, in its turn, leads to difference from the actual stream pattern (velocity, pressure, mixture density) and, as a result, hydrodynamic loads on the tank structure. FLOTRAN module does not allow obtaining washout process and, consequently, distribution of loads on the tank walls at its various time stages, from the start of the device operation to the point of reaching the established process of liquid movement in the tank. In other words, a user cannot analyze and determine maximum dynamic loads acting on the tank structure and moments of time corresponding to them.

The mentioned positive capabilities of ANSYS engineering analysis software for determination of the structure stress condition and, at the same time, its limitations in determination of stream hydrodynamic characteristics made the authors consider the possibility of reaching the solution of the set task within the framework of combined application of the above software and the known software system for hydrodynamic calculations – FlowVision. The determining factor in selection of this software was that, apart from its extended capabilities of stream modeling, which eliminate the above-mentioned limitations, FlowVision has interface of exchanging calculation results with wide-spread strength finite-element software, including ANSYS.

SETTING AND SOLVING THE HYDRODYNAMIC PART OF THE TASK

In order to assess impact of dynamic loads caused by oil jet on PBC wall, stream characteristics during operation of the screw-type mixing device were studied using FlowVision software for hydrodynamic calculations at the first stage of calculation method development. During the study the stream main characteristics and properties peculiar to the above type of the mixing device were determined, and possibilities of facilitating the hydrodynamic part of the general task were substantiated. The study results and analysis were described in detail by the authors in article [3]. Here we are going to point out the following characteristic features.

In order to determine the dynamic loads emerging during mixing of the product stored in a vertical cylindrical steel tank, two-phase (oil and compacted sediment) incompressible fluid model, supplemented with equations of determining the oil-air boundary, named Free Surface in FlowVision was selected as basic hydrodynamic model.

Within this model the following equations are basic: of Navier-Stocks (“Velocity”), turbulent energy and its dissipation (“Turbulence”) as well as determination of the boundary (“Volume of Fluid”). Taking into consideration that it is significant to account for changes of mixture flow properties, the basic equations are supplemented with determination of oil and compacted sediment concentration distribution. Mass concentration model is selected as mass transfer model to describe the process of mixing soluble substances, which corresponds to the components under consideration.

Coming to the description of reaching the solution for determination of stream characteristics and loads on the tank walls, it should be noted that import of the tank original geometry to FlowVision software for solving the set task is performed directly in the form of the finite-element model using special "preparation" methods to be discussed below. Format in which the tank geometry is exported from ANSYS – "*.cdb" – contains all necessary information on structure of the design finite-element grid.

The following should be pointed out. As only the finite-element model having solid elements is available for import to FlowVision, two design areas embedded one into another are formed after the import to FlowVision: internal one corresponding to the tank volume and external one which, along with the tank volume, includes volume of the finite-element cells. Naturally, only the internal design area should be used for calculations.

The essence of using the finite-element model in hydrodynamic calculations is to form on the basis of the calculation (while being in FlowVision) the loads on the tank walls required in our case directly on facets of the design finite-element grid.

It is achieved due to application of progressive subgrid resolution method in FlowVision. Application of this method allows for the design finite-solid cells adjacent to the tank walls and bottom to have as external faces, generally speaking, superposition of external facets or their parts of finite-element design cells coming out to the tank inside. At that, the design finite-solid grid generated in FlowVision is constructed only on the basis of meeting hydrodynamic requirements and not related to the finite-element model structure.

Conversion of the loads obtained in the design finite-solid model cells to the facets of the finite-element grid is performed according to the following diagram (see fig. 1) and formulas:

$$\mathbf{F}_j = \sum_i s_{ij}\mathbf{f}_{ij} \quad ,$$

Where: i – cell number, j – facet number, **f**ij – load on fragment with **s**ij area.

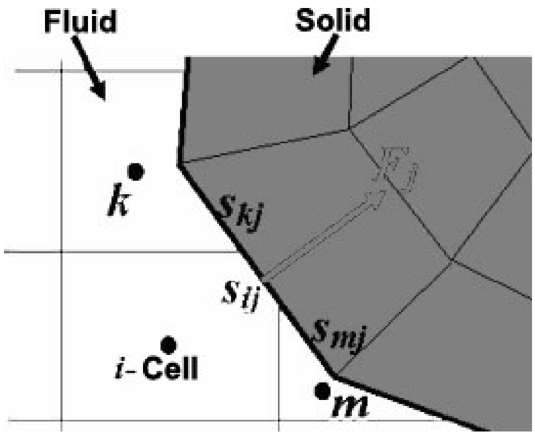

Figure 1. Conversion of loads

After a user has formed the design hydrodynamic model by the method described above, calculation is made and stream characteristics and loads (pressure) on the tank walls are determined depending on the time from the moment of switching on the mixing device. FlowVision allows to determine all pressure components, both hydrostatic and dynamic, caused by the mixing device operation.

After the calculation and analysis of the obtained results a user determines moments of time at which the tank structure stress condition should be calculated and exports the loads on the tank walls and bottom. For export from FlowVision of pressure to be distributed among facets of the finite-element cells, special command of "Geometry" option is used – "Save Side Loadings in File" (see fig. 2). A user can save loads as distributed not only among facets, but also among nodes of the finite-element cells. This capability is required, for example, when exporting temperature distribution in conjugate heat exchange tasks for further setting of thermal stresses in structure.

Having selected the required type of command, a user marks a physical variable for export in the dialog box of variables selection (see fig. 3). As shown on the figure, all physical values involved in the calculation are available for export. Moreover, a user can export a whole set of physical variables by having them recorded in one file. For this purpose, all the components should be just selected one after another.

Having selected a variable (set of variables) and confirmed the selection by pressing "OK" key, a user goes to the dialog box of saving the load calculation results on facets of the finite-element cells where he specifies file name and its location on the hard disc.

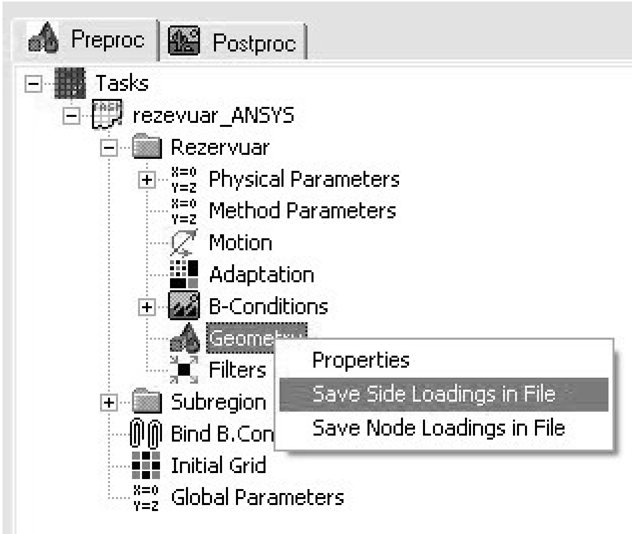

Figure 2. Commands of export of physical variables of hydrodynamic calculation

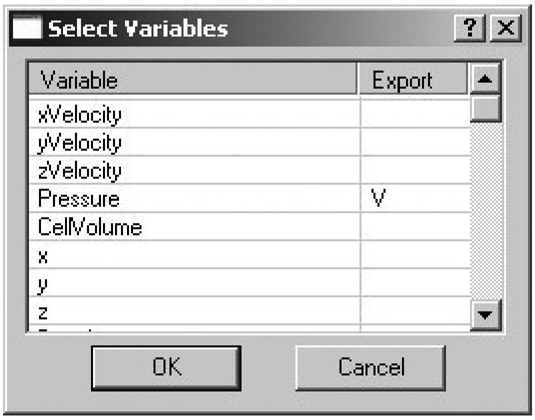

Figure 3. Selection of variables for export

Format of recording the calculation results in the file is text format. Recording in the file is made line by line for each finite-element cell having facets which come out to the tank inside. The line contains information on element, side the load is applied to, load value. The loads are imported to ANSYS from the above file after the lines in the file are supplemented with necessary service information. The essence of converting structure of the lines in the file with the loads will be discussed in the next chapter.

SETTING AND SOLVING THE TASK OF DETERMINATION OF THE TANK STRUCTURE STRESS CONDITION

In order to study the tank structure behavior at loads emerging during washout, model of vertical steel cylindrical tank PBC-5000 with “Diogen-700” device installed in accordance with РД 153-39.4-057-00 [4] at the lower ring of the tank on the oval manhole cover [5] was created using ANSYS finite-element software for engineering analysis.

For determination of structure stress condition, ANSYS software system has extended capabilities of constructing finite-element models. In particular, they include the capability of modeling thin-walled structures using shell finite-elements, which is convenient for solving the set task. The constructed model representing a cylinder was divided into finite elements of SHELL63 type.

When preparing the tank model in ANSYS for its import, there were complications related to impossibility to transfer shell finite elements to FlowVision software. Using solid finite elements at the first stages of the study for modeling and transfer of volume of the liquid stored in the tank to FlowVision did not lead to the desired result due to unavailability of commands in ANSYS for transfer of loads between finite elements of different types.

In order to solve the above problem, special “preparation” of the finite-element model was applied – creation of additional structure using 10-node solid finite elements SOLID92 (see fig. 4). Model of the tank created in ANSYS represented a thin-walled cylinder with its internal or external surface reproducing the shape of PBC tank.

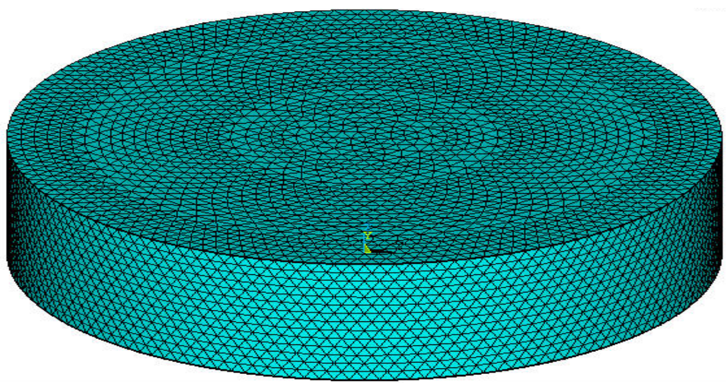

Figure 4. Tank model

Thickness of the upper and lower parts of the solid body was 0.1m, of the cylinder wall – 0.15m, which allowed to divide the structure into finite elements of the above type. Characteristics of the material were specified so that they had no impact on rigidity of the tank: coefficient of elasticity was 5 MPa. For import of the model to FlowVision, Preprocessor-Archive Model-Write-File.cdb options were used. This structure was imported to FlowVision software.

Then, as described above, within the basic hydrodynamic two-phase model of incompressible fluid, the hydrodynamic part of the task was solved in FlowVision. As a result, loads at the facets determined by calculation in FlowVision were exported in special format, as a text file. This file was converted into a file containing SFE commands of ANSYS software (see fig.5). The commands were read in ANSYS, and respective loads were applied to the solid shell model of the tank. Then, using shell finite elements SHELL63 with specified constants and properties of the material corresponding to steel, strength calculation was made. It allowed to determine stresses and shifts of PBC-5000m^3 tank wall.

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SFE,1,2,PRES,1,20088.7
SFE,2,2,PRES,1,12062.6
SFE,4,2,PRES,1,9274.24
SFE,5,3,PRES,1,0
SFE,9,4,PRES,1,9625.27
SFE,11,2,PRES,1,12206.1
SFE,12,1,PRES,1,11897.5
SFE,14,2,PRES,1,2109.84
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Figure 5. Fragment of file with loads

CONCLUSION

So, joint application of ANSYS and FlowVision engineering analysis software combined with developed simplifications of the hydrodynamic model and methods of preparation of the shell finite-element model allowed to find a way of correct solving of the task on study of the tank structure behavior at loads emerging during washout without any limitations.

It is also important that division of the general task into two allowed not only to solve each of them in its specialized software, but also to use all possible software and hardware for solving each of the tasks.

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