Evaluation of strain-stress state of vertical tank reinforced by carbon tyre based on numerical researches in ANSYS PC

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Abstract. The article presents the results of numerical studies of the stress-strain state of the models of a vertical cylindrical tank with corrosion wear and with the strengthening of the wall of the first ring by an external and internal composite tyre. Based on the results of the studies, the maximum percentage of corrosion wear of the wall of the first ring of the tank have been determined, and the dependences of the influence of the installation of the internal and external carbon composite tyre on the stress-strain state have been obtained.

1. Introduction

Nowadays, the greater part of the operating tank farm of steel tanks of the hydrocarbon process industry of Russia has exceeded the regulatory time limit. Long-term operation of capacitive equipment without timely overhaul results in defects that reduce operating reliability [1]. The current task is to develop new methods or adapt existing ones for the restoration of building structures, using modern materials with high operational characteristics.

The use of carbon composites in reinforcement of supporting structures is increasingly attracting researchers in this field every day [2, 3]. This phenomenon is primarily due to significant technological advances in the production of carbon fibers and synthetic binders. Adhesive bonding of metals to other materials becomes a very reliable method of joining elements in items and structures, and has a number of advantages over other types of bonding. It should be noted that riveted, bolted and welded joints have an uneven distribution of stresses at the junction, and are also weakened by holes under rivets and bolts, and increase the weight of structures. The bonding of metals and alloys...
by welding results in internal stresses in the weld zone and decrease in heat treatment strength. Adhesive joints have uniform stress distribution in bonded materials and are made by unfired method. The works [4-7] show the results of tests of thin steel plates, reinforced with carbon plastic layers at cyclic quasi-static load. The authors conclude that the use of carbon plastic laminates can significantly increase yield strength, ultimate strength and stability. Fiber orientation is an important factor in shear enhancement. The greatest shear strength and resistance can be obtained by applying the basic orientation of carbon plastic laminates along the direction of the stress fields. When the thickness of the adhesive changes, the failure mode changes from cohesive failure to interfacial destruction of the adhesive on the steel surface. For cohesive fracture bonded joints, the maximum load increased as the adhesive thickness increased from 1 to 2 mm.

2. Analysis of defects, arising during operation of tanks.
Statistics show that the main cause of the failure of oil tanks is the corrosive wear of the surface, coming into contact with the corrosive (figure 1) [8,9].

![Figure 1. Statistics of VST failures](image)

The analysis of safety expert review showed that the most of the corrosion defects are located on the bottom, corner weld joint and the first ring of the tank wall, which is confirmed by the frequent replacement of elements during overhaul repairs. The highest percentage of corrosion wear in the wall thickness was observed at the height of up to 30 cm from the level of the corner weld joint (Figure 2). The main cause of corrosion damage is the presence of bottom water at these levels. According to regulatory documents, GOST R 51858-2002 [10] in particular, the mass fraction of water is not more than 0.5% for the first and the second groups of oil, and not more than 1.0% for the third group.

The numerical research program provides three design models of tanks:
- vertical stock tank (VST) with corrosion wear of the inner surface of the first wall ring on a significant length in the area of abutment to the bottom. The nature of corrosion is the groups of shells that turn into continuous strips, as well as point depressions of the pitting type.
- VST with one inner tyre with the height of \( b = 1300 \) mm, made of carbon unidirectional tape Tape 230 on epoxy binder Resin 230.
- VST with two tyres, the inner one with the height of \( b = 1300 \) mm and the outer tyre with the height of \( b = 300 \), located at the height of 500 mm from the corner weld joint and made of carbon unidirectional tape Tape 230 on epoxy binder Resin 230.
The efficiency of the device of one external steel shroud ring in restoring the bearing capacity of the tank is justified in the work of M.A. Tarasenko [11]. According to [12-14], the maximum effective stresses of $\sigma_{\text{max}}$, MPa, in the tank wall should not exceed the values, specified in Table 1.

### Table 1. Maximum allowable stresses in tank elements.

| For lower wall ring, MPa | For other rings of wall with bottom, MPa | For junction, MPa |
|-------------------------|----------------------------------------|------------------|
| Maximum allowable stresses under operating conditions | 176,67 | 201,90 | 302,86 |

### 3. Basic data for creating tank simulation models.

To perform VAT calculations, the ANSYS software-computing complex is used, which allows:
- creating FE model and determine stress-strain state of tank structures: tank wall, bottom, welded joints;
- setting distributed, local, hydrostatic and inertial loads;
- setting loads from previously applied stresses (welding stresses);
- solving elastic (linear) and elastic-plastic problems (nonlinear);

To build a geometric model of the tank, a typical design of RVS 5000 m³ “TP 704-1-27” was adopted [15].

The finite element model of the tank was constructed, using shell elements SHELL181, having a number of features, inherent in thin-walled shells. Face meshing is used to create a uniform ordered mesh on the surface of the tank wall. The size of the finite element mesh was 0.05 m (square side). In order to improve the accuracy of calculations in the wall and bottom interface, the FE grid was thickened 4 times, using the Refinement function [16].

Statistical information of finite element tank model is given in Table 2.

### Table 2. Statistical information of the finite element model.

| Total |
|-------|
| nodes | 332361 |
| elements | 326905 |
| material properties | 2 |
Hydrostatic pressure (figure 3) and overpressure (figure 4) were used as tank loads.

Figure 3. Hydrostatic pressure on VST wall from stored product.

Figure 4. Excessive internal pressure on VST wall.

4. Results of numerical calculation.
Based on the results of the conducted studies, the dependence of the strains $\alpha_{eq}$ on the value of corrosion wear of the wall of the first ring in the range from 0 to 40% was obtained with reinforcement by carbon composite tyres and without reinforcement (figure 5). There is also a diagram of the dependence of deformations (wall deviation from vertical) of the tank wall on the value of corrosion wear for three design models.

Figure 5. Stresses in the first wall ring at corrosion value from 0 to 40%.
Analysis of the obtained data showed that the excess of permissible stresses occurs with continuous corrosion of the first wall ring, exceeding 25%.

Installation of one internal carbon composite shroud, with corrosion of 25%, allows to reduce the level of maximum stresses in the wall by 7.25% and deformations by 1.25%.

Combined installation of internal and external carbon composite shrouds with similar corrosion percentage showed a decrease in wall stresses by 8.27% and deformations by 1.625%.

5. Conclusions.
The application of the internal carbon composite shroud can be effectively used in restoring service suitability and extending the life cycle of tank with corrosion wear of not more than 40%.

The use of a combined device of internal and external carbon composite shrouds does not significantly reduce the equivalent stresses, arising in the walls of the first ring.

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