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Evaluation of Stress-strain State of Steel Cylindrical Tank with Dent Defect

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Abstract

Oil steel vertical tanks are among the most dangerous objects in the system of main pipeline transport of oil. Various type defects may appear during maintenance of the tanks. Defects reduce the reliability of the tank and lead to accidents of varying severity. It should be noted that a significant part of the tank farms of Russia have practically exhausted its service life (25-30 years) or haves defects, which are not permissible according to the standard documentation. On the one hand, overhaul or dismantling requires significant material costs. On the other hand, the occurrence of accidents at cylindrical steel tanks in most cases is accompanied by significant loss of oil, ground contamination and loss of life. Thus, the problem of prediction of operational reliability and durability of tank structures is actual; its solution will ensure accident-free operation of tanks. The work is devoted to solving the problem of the safety operation of steel vertical cylindrical tanks by the example of the analysis of stress-strain state of steel vertical tank with capacity 5000 m^3 with a defect the dent with allowance for its operating loads, geometry and defect location in the tank structure using finite element modelling.

Keywords: Steel Vertical Cylindrical Tank, Stress-strain State, Safe Operation, Operational Defect, Finite Element Method

NOMENCLATURE			
FEM	Finite element method	μ	Poisson's ratio
σ_τ	Yield stress (MPa)	E	Modulus of elasticity, Pa
σ_B	Ultimate strength (MPa)	ρ	Density, kg/m^3.
σ_e	Equivalent stress (MPa)		

INTRODUCTION

Steel vertical tanks for storage of oil and oil products are thin-walled metal structures working cyclically in a complex stress-strain state. Tanks are exposed to cyclically varying loads, temperatures and aggressive working fluids. Constructive defects occur in the tanks while its operation. They can be caused by structural, technological and operational factors. Often, there is the problem of structural assessment of the tank with defects during the technical diagnosis of steel vertical tanks.

Currently there are many research works on the stress-strain state analysis of steel vertical tanks with defects [1-6]. It should be noted that the authors of these works point to the imperfection of the methods of calculation of the stress-strain state of oil tanks. These methods do not allow to assess the real residual life of operated tanks. This is due to the fact that calculations of stress-strain state of tank by the normative documents [7-10] do not take into account the structural features of the steel vertical tank, operating conditions, external and technological factors, the presence and location of the defects. Analysis of accidents on steel vertical tanks [11-13] found that the dents are one of the most common defects in the geometry of the tank wall. Various constructive “soft” defects such as buckles and dents, bulges, deviations from the cylindrical shape may occur during maintenance of oil tanks. These defects are formed due to differential settlement of tank foundation, nonadherence of mounting technology or technology of repair. “Soft” defects can cause the strength and stability of tank bed and thus reduce the service life and reliability. Dent leads to stress concentration in the area of the defect under internal pressure. It is the cause of flaps. The emergence of such defect can cause the loss of strength and stability and a disruption of integrity of the tank.

It should be noted that the normative documents [9, 14-17] limit allowable value of depth of the dent rather strictly. However, neither the geometric dimensions of dents (width, form) nor their location on the wall of the tank height are not taken into account. The experience of many years of accident-free maintenance of the tanks with the soft defects, which are not satisfying the requirements of the document [9], shows a lack of sufficient validity of the imposed restrictions, which is also confirmed in papers [1,2, 18]. According to normative document [9], when a dent or bulge is detected, the tank operation is possible only if the stress-strain state calculations are made. And it is proved that limit stresses in the wall of metal structure are absent and the defect does not lead to a loss of strength and stability of the tank wall.

The task of this research is to analyze the influence of the defect “dent” on the stress-strain state of the tank and nozzle. It is necessary to justify the possibility of extending terms of safe operation of the tank before the planned repair.

Viewed tank is vertical cylindrical steel tank with pontoon, the capacity of the tank is 5000 m^3. It is used for storage of gasoline. The parameters of the tank are presented in table 1.

Table. 1. Vertical cylindrical steel tank RVSP-5000 specification

Parameter	**Value**
Diameter of the tank	22.817 mm
Height of the tank	12 m
Height of the course	1.5 m

Maximum level of gasoline	10.26 m
Thickness of the first shell course	9.40 mm
Thickness of the second shell course	7.30 mm
Thickness of the third shell course	6.30 mm
Thickness of the fourth shell course	5.80 mm
Thickness of the fifth - eighth shell courses	4.80 mm
Gasoline density	770 kg/m^3
Steel	S235J2G3 (σ_τ =245 MPa, σ_B =370 MPa)

During the visual and measuring control of the tank the dent was found in the wall at a height of 8483 mm from the bottom. The sizes of the dent are: the minor axis - 420 mm; major axis - 1100 mm; deflection (depth) - 39.1 mm.
Also a defect such as a dent was detected on the inlet/outlet nozzle of the tank.

Table. 2. Inlet/outlet nozzle of the tank RVSP-5000 specification

Parameter	Value
Nominal diameter	530 mm
Wall thickness	10 mm
Length of the pipe	0.5 m
Steel	S235J2G3 (σ_τ =245 MPa, σ_B =370 MPa)

The sizes of the dent on the nozzle are: minor axis - 14 mm; the major axis - 26 mm; depth - 7 mm. This defect occurred due to a drop of the hook of construction crane during installation of the tank roof. It is assumed that there is no combination of external operational loads, which can cause the limit state in the nozzle of the tank. In addition, delivery of construction elements of the tank, weather conditions, financial costs do not always allow to repair the tank on time. In this regard, determination of the operation of the nozzle with a dent is important and actual. It can help to postpone the replacement of the defective nozzle to the next overhaul.

SOLUTION PROCEDURES

It is necessary to determine the possibility of further safe operation of the tank and the nozzle with dents. It is done by comparing the maximum equivalent stress with the yield stress of the steel.

Determination of Stress-strain state in The Tank Wall

Stress-strain state calculation are performed by finite element method (FEM) in the SIMULIA Abaqus software. During the creation of the tank model the properties of steel were used: E=2.1·10^{11} Pa, μ=0.3, ρ=7850 kg/m^3. Actual thicknesses of the wall of the tank were assigned to Shell-elements. The following loads and boundary conditions were applied to the tank model: distributed weight of the roof and equipment of the tank, snow load, hydrostatic pressure corresponding to the filling level (10.26 m), rigid fixing of the tank bottom (encastre), symmetry condition, overpressure of oil vapors, the strength of the gravitational effect. Due to FEM nominal hoop, longitudinal and equivalent stresses, deformations were identified (Fig.1).

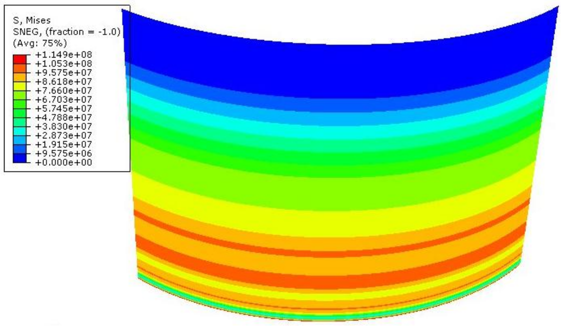

Figure 1: Distribution of equivalent stress in the tank wall

Simulation of a dent in the tank wall

Contact problem was solved for modelling a dent in the tank. Dent was simulated by subjecting the spherical surface on the tank wall. Contact problem was limited to the determination of the radius of the hemisphere and the force. Steel hemisphere was created in Abaqus after defining the radius and strength. It was positioned in the assembly model at the height 8483 mm from the bottom of the tank to create the dent with desired depth. Then the equivalent stress (von Mises) and the moving surface of the tank wall were determined (Fig. 2, 3).

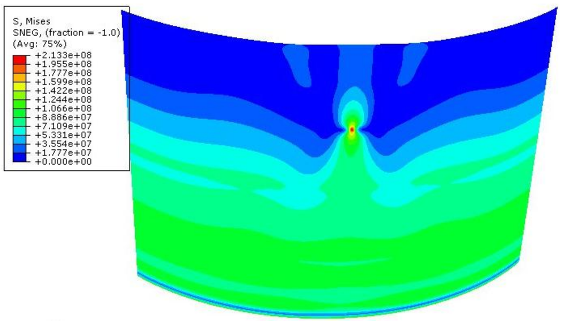

Figure 2: Equivalent stress in the tank wall with the dent

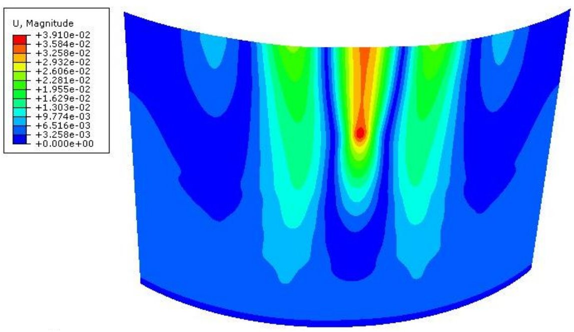

Figure 3: Displacements of the surface of the tank wall with a defect "dent"

The maximum equivalent stress is in the center of the dent and its value is 213.3 MPa.

Simulation of a dent in the nozzle

Also an emergency situation was simulated. Formation a defect "dent" on the nozzle of the tank due to a drop of the hook of construction crane was modeled.

Analysis of the effect of the dent was realized by the solution of the dynamic problem. The impactor, realizing the role of a hook, was created. The impactor deforms the surface of the pipe during the fall (Fig.4).

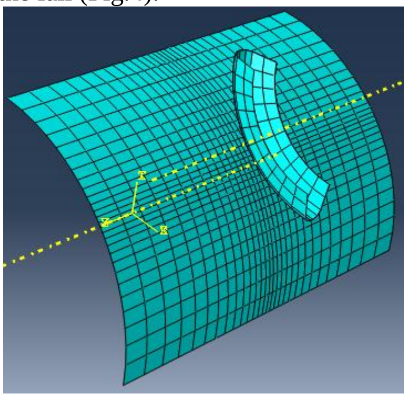

Figure 4: Finite element model of the nozzle with impact

The equivalent stress (von Mises) and the plastic strain in the pipe wall were determined during simulation (Fig. 5, 6).

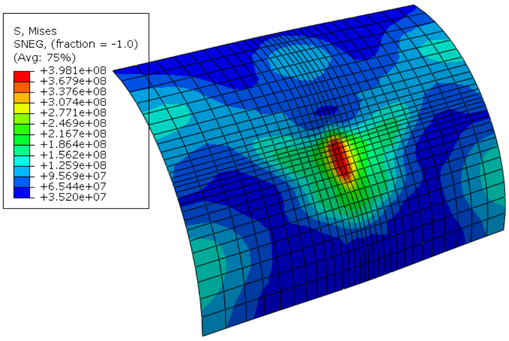

Figure 5: Equivalent stress in the pipe with the dent

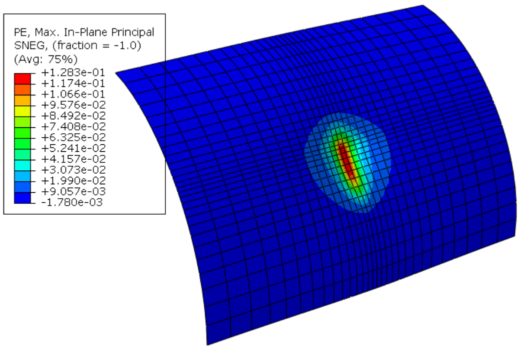

Figure 6: Distribution of plastic strain in the pipe wall

RESULTS OF SIMULATION

According to the paper [3], the restriction is set for the limit stresses in the wall of steel vertical tank. The equivalent stresses are compared with the yield stress of steel (1):

$$\sigma_e \le \sigma_\tau \quad (1)$$

It is found that the maximum equivalent stress arises at the center of the dent. Its value is 213.3 MPa. Consequently the condition (1) for the tank with a dent is satisfied. Thus, strength condition for the dent in the wall of the tank is executed. Area of the tank wall with a dent does not turn to unallowable plastic deformation. In addition, the critical depth of the dent was founded (58.05 mm), which leads to unallowable plastic deformation. So, it is necessary to put the tank out of action for the repair.

The value of maximum stress in the contact area of the nozzle with crane hook is 398.1 MPa and displacement is 22.57 mm. Changing of values of the wall displacement and equivalent stresses in nozzle is shown in Fig.7.

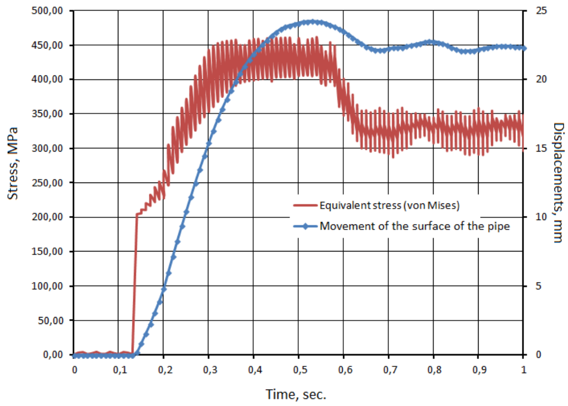

Figure 7: Distribution of stresses and displacements in the center of the dent

As can be seen from the plot in Fig.7 stress jump to 200 MPa is occuring at the time of the fall of the hook on the nozzle (0.12 seconds). Then stress increment is appearing in flowing mode. In the range from 0.3 to 0.56 seconds stresses are remaining at the same level - 425 MPa. And then stresses are reducing and remaining constant at 340 MPa at the end of the step of calculating. In the range from 0.3 to 0.56 seconds stresses are increasing under the weight of the hook. After completion of the contact surface of the nozzle with the hook, stresses are falling off, and displacements of the surface of the pipe is reducing under internal pressure (from 28.5 mm to 22.5 mm). Plastic deformation of the nozzle is 12.83%. Therefore, the metal of the nozzle has moved from the deformation to the plastic unallowable deformation, which is forbidden in the tank operation.

CONCLUSION

Using the finite element modeling analysis of stress-strain state of the tank with dent in the wall and the nozzle was performed. It gives opportunity to determine possible safe operation of the tank before puting out of action to the scheduled repair. The analysis results show that the detected dent in the tank wall does not cause unallowable stresses.

Dent on the nozzle leads to the formation of limit stresses and requires urgent replacement of the nozzle.

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