Numerical analysis of the cylindrical rigidity of the vertical steel tank shell

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Abstract. The paper deals with the study of rigidity of a vertical steel cylindrical tank and its structural elements with the development of inhomogeneous subsidence in ANSYS software complex. The limiting case is considered in this paper: a complete absence of a base sector that varies along an arc of a circle. The subsidence zone is modeled by the parameter n. A finite-element model of vertical 20000 m^3 steel tank has been created, taking into account all structural elements of tank metal structures, including the support ring, beam frame and roof sheets. Various combinations of vertical steel tank loading are analyzed. For operational loads, the most unfavorable combination is considered. Calculations were performed for the filled and emptied tank. Values of the maximum possible deformations of the outer contour of the bottom are obtained with the development of inhomogeneous base subsidence for the given tank size. The obtained parameters of intrinsic rigidity (deformability) of vertical steel tank can be used in the development of new regulatory and technical documentation for tanks.

1. Introduction

In terms of rigidity, all structures are divided into 3 main types: absolutely rigid, when the deformability of the structure is negligibly compared to the deformability of the base, and the structure can be considered as undeformable; absolutely flexible, when the deformability of the structure is so great that it freely follows the deformations of the base; of finite rigidity, when the deformability of the structure is commensurable with the deformability of the base and they deform together, which leads to a redistribution of the acting stresses.

Many researchers attribute tanks to structures with high flexibility. In this case it is assumed that a bottom and wall of a tank are deformed together with the ground base on which it rests [1-5]. It is assumed that the wall and all metal structures are deformed to the same degree after the base subsidence, which leads to their destruction due to considerable plastic deformations in the metal. They do not take into account the cylindrical rigidity of the shell of rotation, which is the VST wall, as well as other stiffeners: annular plates, stiffening rings, beams and roofing.

The authors attempted to estimate the intrinsic rigidity of tanks using numerical methods. Impacts from the operational loads of the tank are distributed not only along the central part of the bottom, but also along the reinforced concrete foundation ring, therefore we must take into account the joint operation of various VST structure elements: wall, annular plate, stiffening ring, beams, roofing[6-7].

The task was to calculate the values of the movements of the VST elements with the inhomogeneous subsidence of the outer contour of the bottom (excluding the "roll" type subsidence with a different development mechanism), as well as stresses for various elements of the tank resulting from the operational loads. At present, there are diagnostic methods that allow determining with high precision the absolute elevations of the geometric position of the VST structure elements [8-11]. In addition, new computational software packages have appeared on the basis of the finite element method, allowing us to determine with sufficient accuracy the deformations of metal structures from the impact of operational loads. Knowing the parameters of the tank's intrinsic rigidity, it is possible to correlate them with the results of a diagnostic survey of the inhomogeneous subsidence of a particular object, thereby solving the engineering problem of assessing the technical state of the VST under study and the need to bring it to repair.

2. Methods

To study the intrinsic rigidity of a vertical steel tank, the authors propose to use numerical methods realized using the software product ANSYS [12, 13]. The calculation is based on, as a test case to justify the method, the tank RVS-20000m^3 in accordance with the standard project 704-1-60. In the calculation model, the following elements are taken into account: foundation ring, wall, annular plates, central part of the bottom, support ring, roof dome. The model consists of beam (BEAM4, BEAM188), shell (SHELL181) and "contact" (CONTA175, TARGE170) finite elements. Material of the VST metal structures is a structural low-alloy steel 09G2S with the yield strength σ_{yield} = 325 MPa.

To simulate contacts, the authors applied the extended Lagrange method, which is the main algorithm for solving problems with contacts of elements of a mixed type. It is based on an iterative representation of the method of penalty functions. The contact pressure and frictional stress increase during the execution of equilibrium iterations until the final penetration is less than the permissible penetration value. The method is effective for modeling a "surface-to-surface" contact and a "node-to-surface" contact, allowing accurate results to be obtained in most contact tasks.

In [3], the adequacy of the proposed FE model was tested by solving a well-known analytic axisymmetric problem in a linear formulation [14]. The results of the numerical solution implemented in the software complex ANSYS and the analytical one differ by not more than 2%, which indicates the possibility of using the proposed model for calculating rigidity parameters.

The authors of the article propose to determine the parameters of the tank's intrinsic rigidity by modeling the inhomogeneous subsidence of the outer contour of the bottom. To set the size of the subsidence zone, we use the dimensionless parameter n:

$$n=\pi R/L \tag{1}$$

where L – the arc dimension of the inhomogeneous subsidence zone;
R – the tank radius.

The values of the parameter n vary from 1 to 6, which corresponds to: the angular dimensions of the subsidence zone from 180º to 30º, the arc dimensions of the subsidence zone from 72 m to 12 m.

According to the set dimensions of the parameters n = 1, n = 2, n = 3, n = 4, n = 5, n = 6, the calculations of the tank stress-strain state are alternately performed, and the cases of the emptied and filled VST in age levels are separately considered. When calculating the inhomogeneous subsidence, a number of boundary conditions and loading conditions are taken to determine the parameters of intrinsic rigidity.

Loads are applied to the tank from the weight of stationary equipment, snow; the tank is rigidly fixed along the lower planes of the central part of the bottom and the foundation ring, the contact problem is solved with setting the value of the coefficient of subgrade reaction.

To simulate the subsidence area, a segment of a foundation ring of a given size (the ground is removed) is cut out in accordance with the formula (1), thereby creating "sagging" of the annular plate and walls in the zone of the corner weld joint, i.e., in this segment there is no contact with the base and the structures above the subsidence zone are given freedom of movement. Figure 1 shows the model RVS-20000 with a subsidence zone with the arc dimension L = 12 m.

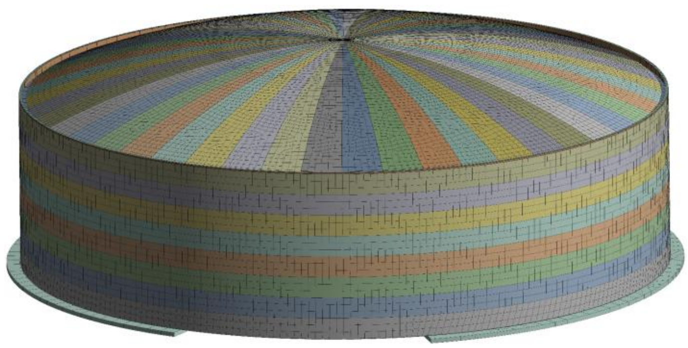

Figure 1. Model VST-20000 with a subsidence zone.

3. Results

The obtained subsidence values depending on the size of the subsidence zone are presented in Table-1.The maximum possible subsidence levels of the outer contour of the tank bottom for the subsidence zones are given in figure 2 and figure 3. For comparison, the numerical solution obtained by I.V. Slepnev, using the “Lira” software package is given, which has a number of simplifications and assumptions [15]. It should be noted that for this combination of design parameters of RVS-20000, the properties of 09G2S steel and the combination of structural loads taken from the project, the resulting deflections are maximum and cannot increase with any change in the properties of the base or foundation.

Table 1. Vertical displacements of the points of the corner weld joint within the subsidence zone.

Value of parametern	Tank filled to the design mark, mm	Emptied tank, mm	Emptied tank, numerical solution by I.V. Slepnev, mm
n=6	17.3	0.82	0.07
n=5	17.5	1.1	0.1
n=4	17.6	1.7	0.12
n=3	18.1	2.12	0.2
n=2	20.3	2.4	0.3
n=1	42.1	13.2	0.4

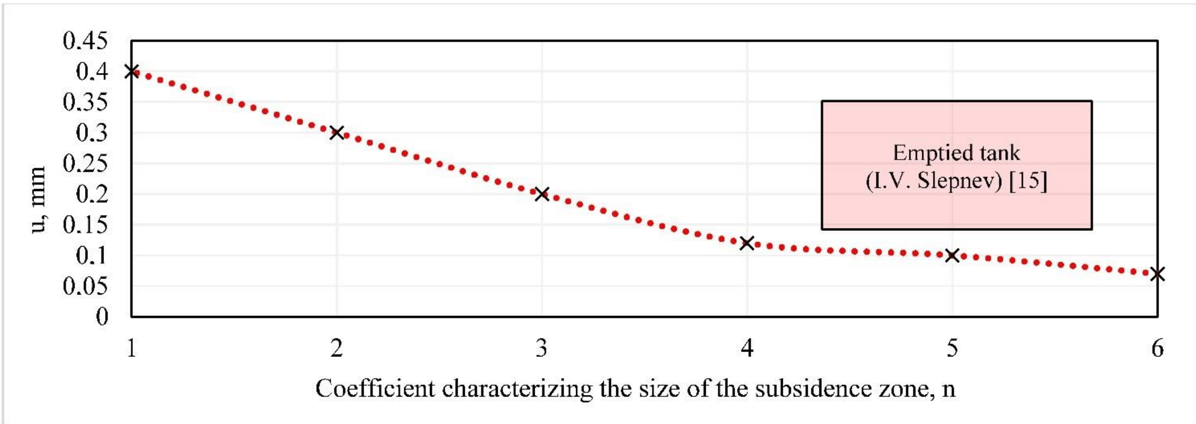

Figure 2. Permissible subsidence of the outer contour of the bottom for a subsidence zone n (according to I.V. Slepnev).

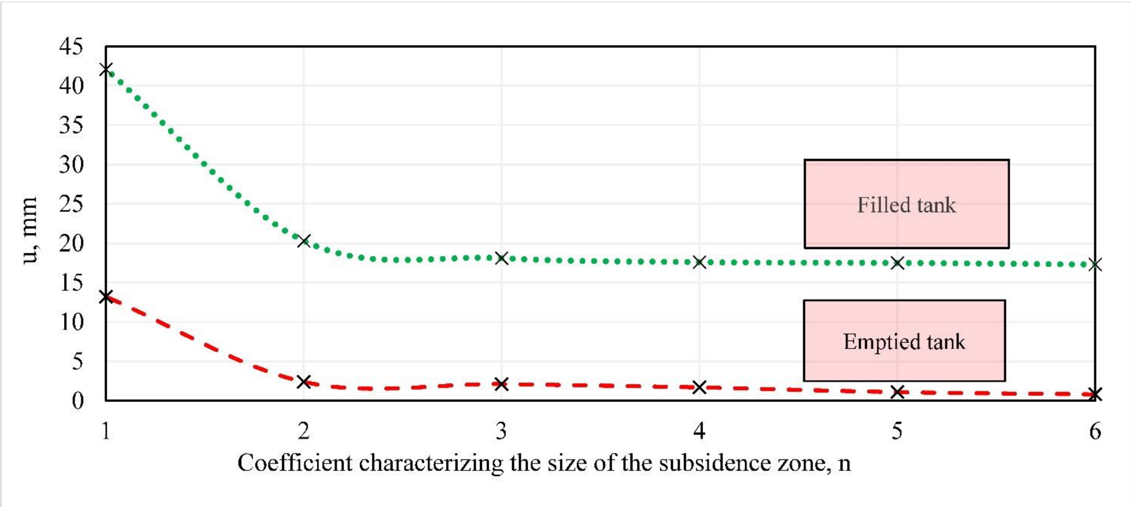

Figure 3. Permissible subsidence of the outer contour of the bottom for a subsidence zone n (ANSYS).

Figure 4 shows the diagram of the displacements of the VST structures for the inhomogeneous subsidence with the value of the parameter n = 1. To demonstrate the nature of the change in the strain fields, the radial scale is increased in comparison with the axial one.

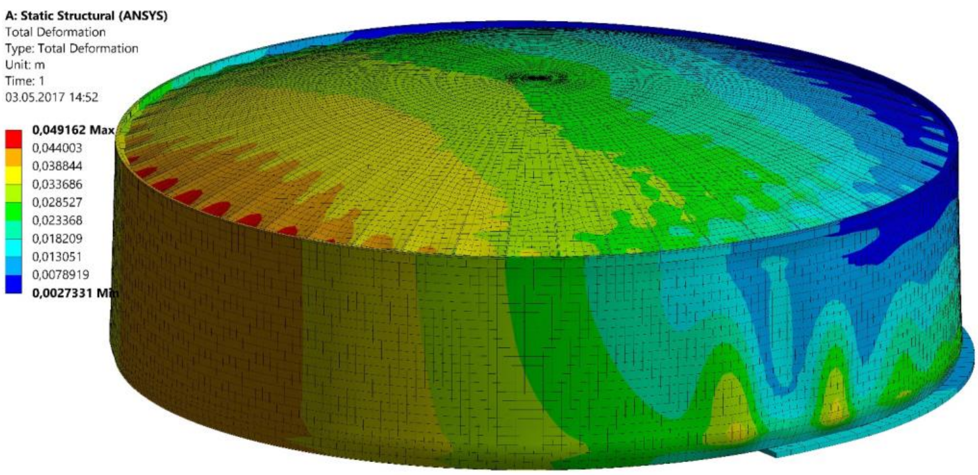

Figure 4. Deformations of VST structures at n = 1.

4. Discussion

Having investigated the parameters of intrinsic rigidity and limiting values of deformations of the outer contour of the bottom under the influence of operational loads, it is possible to propose a qualitatively new method for analyzing the results of the diagnostics performed.

Thus, analyzing the nature of deformation of the outer contour of the bottom for emptied and filled tanks, it can be concluded whether there is a case of inhomogeneous subsidence of the tank, or there is reason to assert that construction and installation works were substandard. In addition, knowing the ultimate deformation capabilities of the tank, based on the leveling results, it is possible to qualitatively assess the state of the VST and draw conclusions about the need for repair of this tank.

5. Conclusions

A numerical model of RVS-20000 was developed in the ANSYS software package, to study non-axisymmetric problems, which takes into account all the structural elements that affect the rigidity of the tank.

Numerical results of the stress-strain state of RVS-20000 structures are obtained, which characterize the rigidity of the tank in the emptied and filled states from the impact of operational loads.

The obtained parameters of intrinsic rigidity of VST allow us to develop a technique for assessing the technical state of the structure with the development of inhomogeneous subsidence of the outer contour of the bottom, as well as to formulate proposals for clarifying the requirements of the current regulatory and technical documentation for other tank sizes.

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