Analysis of stress-strain state of support ring of vertical steel tank RVS-20000

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Abstract. The refined finite element model of the joint of a fixed roof with a support ring for a large-size vertical steel tank RVS-20000 is executed. It considers the real geometry of metal shell plates - in accordance with the TP-704-1-60 design, geometric and physical nonlinearity, and features of the non-axisymmetric design loading scheme of the structure. Dependences of the SSS parameters of the support joint design on the size of the subsidence zone of the outer contour of the RVS-20000 bottom are obtained. It is established that at the value of subsidence zone coefficient \( n \leq 1 \), a region of critical values occurs, exceeding which leads to the appearance of unacceptable plastic deformations of metal structures. The authors performed interpretation of the postprocessing of the finite element analysis, as a result of which the dependences of the parameters of the stress-strain state on the value of the zone of warping were obtained. The graphs of the dependence of the values of strains and stresses of the metal structure of the support ring on the size of the subsidence zone along the arc of the outer contour of the bottom are presented.

1. Introduction

The design of the vertical steel tank is a cylindrical shell, bounded by a foundation base along the bottom contour and a fixed beam-sheet cover over the top. The technical and operational characteristics of this structure allow the storage of a liquid product, the weight of which can be up to 50 times the weight of the structure itself. Many years of expertise [1-3] show that in the absence of off-design loads caused by the action of various factors, the tank can be operated without fail for more than 30 years, with interruptions for routine maintenance and diagnostics. The main negative factors that can lead to premature violation of the technical condition of the vertical steel tank (VST) are: errors at the stage of construction and design of the VST; change of the technological scheme of pumping, an increase of operational loads on the structure; change of the hydrological conditions of the tank site. These factors under certain circumstances lead to the appearance of non-axisymmetric off-design loads which can cause the occurrence of limit states in the metal structures of the tank.

The development of tank subsidence, especially its uneven component, is the most common cause of VST accidents according to [4]. If uneven subsidence is detected, the nature of the tank body deformation can not be accurately calculated despite the existence of an extensive regulatory and technical base for the repair and operation of large-size VST. Therefore, the authors investigate the effect of individual structural elements on the total SSS of the structure when the uneven subsidence of
the base develops. The support ring, according to [5, 6], is subjected to significant loads during the non-axisymmetric deformation of the tank body. However, the numerical dependences of the SSS parameters of the metal structures of the support ring on the magnitude of uneven subsidence are not currently investigated.

2. Methods
The authors suggest performing numerical modeling of the upper support joint of RVS-20000 in the ANSYS software suite which implements the finite element method (FEM). The development of uneven subsidence is proposed to be modeled by cutting out a segment of the foundation ring, as a result of which a subsidence zone is formed, the dimensions of which are determined by coefficient n according to [7-8]. Thus, the most unfavorable case of subsidence is considered in which the contact of the annular plate and the corner weld joint with the support is completely lost. It is proposed to consider range n = [1..6], which corresponds to the values of the subsidence zones from 12 to 72 m. The beam and shell end elements are used in the simulation: SHELL181 - for constructing sheet structures, BEAM4 - for building beam elements of the roof frame [9, 10]. The contact interaction of metal structures of the corner weld joint, a foundation ring and subgrade is taken into account, the properties of which are set by the subsoil reaction coefficient and in this case equal to 200 MN/m³.

Figure 1 shows the design scheme indicating the main structural elements of the VST, the subsidence zone, the direction of deformation of the stiffening ring structure, zones of elastic contact of the foundation bottom with the subgrade.

It is proposed to determine deformations and effective equivalent stresses in the design of the stiffening ring at different values of the subsidence zone.

3. Results and Discussion
Figure 2 shows the results of finite element simulation - deformation of the stiffening ring at the size of subsidence zone n = 1, n = 2, n = 6, respectively. In this case, scale factor x200 was used for visualization, which makes it possible to visually evaluate the deformation pattern of the support ring segments. Thus, the section of the ring located above the zone of warping has a U-shaped bend when
considering the frontal plane of the projection which is tangent to the wall in the place of the subsidence zone.

Figure 2. Deformations of the stiffening ring at the size of the subsidence zone: a) n = 1; b) n = 2; c) n = 6.
The authors performed interpretation of the postprocessing of the finite element analysis, as a result of which the dependences of the parameters of the stress-strain state on the value of the zone of warping were obtained. Figure 3 provides a graph of the dependence of the deformation values of the metal structure of the support ring on the size of the subsidence zone along the arc of the outer contour of the bottom.

Also, effective equivalent stresses in the support ring were analyzed for different values of the subsidence zone of the outer contour of the bottom of the VST. The graph in Figure 4 determines the permissible stresses (188 MPa) according to the regulatory documentation [6], as well as the critical ones which can cause limit states (325 MPa - the yield point of the 09G2S tank steel) in the metal structures.

![Figure 3](image1.png)

**Figure 3.** Graph of the dependence of the support ring deformation values on the value of the uneven subsidence of tank RVS-20000.

![Figure 4](image2.png)

**Figure 4.** Dependence of equivalent stresses on the value of tank subsidence.

Thus, uneven subsidence of the structure under consideration with parameter \( n < 2 \) causes the growth of effective stresses of the metal structures to the maximum permissible values. However, in this case, the design state of the connection joint of the stiffening ring and the fixed cover is considered. Since the support ring is subjected to significant loads during the deformation of the structural body, it is not known how the off-design elements and various defects of the stiffening ring affect the construction SSS if subsidence develops.
Diagnostic tests of tanks, namely, monitoring the technical state of the upper conjugation joint of roof elements with the stiffening ring, have shown that there are often cases of operation of tanks with non-normative structural elements of the upper joint.

So, to connect the bearing beams with the support ring, backing plates, corners and other unacceptable elements of additional rigidity are used, which leads to concentration of excess stresses when the tank is loaded. Also cases of non-axial fixing of segments of the support ring are known. As a result, a stepped joint is formed with the fitting of plates of different sizes for the weld connection of these segments. Unacceptable metal elements and an increase in the number of welded joints that do not comply with the design reduce the overall reliability of the tank structure.

The resulting stresses from the non-axisymmetric effects of uneven subsidence in the presence of off-design elements can cause excessive stresses in the metal structures of the upper tank support joint. Additional off-design stresses, in turn, entail the risk of occurrence of limit states in the metal and, as a consequence, violation of the serviceability of the entire structure. To avoid this, it is necessary to make additions to the regulatory framework in terms of monitoring the diagnosis of structures of the upper tank joint, the quality of which is not always sufficient to identify defective elements.

4. Conclusion
The refined finite element model of the joint of a fixed roof with a support ring for large-size vertical steel tank RVS-20000 is executed, which considers the real geometry of metal shell plates - in accordance with the TP-704-1-60 design, geometric and physical nonlinearity, and features of the non-axisymmetric design loading scheme of the structure.

Dependences of the SSS parameters of the support joint design on the size of the subsidence zone of the outer contour of the RVS-20000 bottom are obtained. At the value of the subsidence zone coefficient of $n \leq 1$, a region of critical values occurs, exceeding which leads to the appearance of unacceptable plastic deformations of the stiffening ring.

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