Stress-strain state of the pipe-tank system under tank bottom settlement

To cite this article: A Tarasenko et al 2019 J. Phys.: Conf. Ser. 1145 012005

View the article online for updates and enhancements.
Stress-strain state of the pipe-tank system under tank bottom settlement

A Tarasenko¹, P Chepur¹ and A Gruchenkova²

¹Institute of Transport, Industrial University of Tyumen, 38 Volodarskogo Street, Tyumen 625000, Russian Federation
²Surgut Oil and Gas University, branch of Industrial University of Tyumen, 38 Entuziastov Street, Surgut 628404, Russian Federation

Abstract. The article presents a numerical model of a tank with a pipe header unit developed by the authors. The numerical model was developed considering the real geometric shape and size of the object. The model also considers the non-linear properties of the steel from which the tank and pipelines are made. This article solved the contact problem of connecting the pipeline with the wall, considering the fixed joint based on the "bonded" contact. The peculiarities of the contact interaction of pipe header pipelines with sliding supports are considered. The authors developed a design scheme for deformations of the structure under settlement. Thus, according to the results of the calculations, new dependences of the maximum effective equivalent stresses in the metal in the area of pipe header pipelines connection with the wall on the settlement value were obtained. The results obtained reflect the real stress-strain state of the metal structures of the tank under non-axisymmetric loading. The dependences obtained allow us to determine the areas of occurrence of limiting states, in accordance with which an operational decision is made about the need for repair or the possibility of continuing the tank operation, which confirms the practical significance of this study.

1. Introduction

Studies of the stress-strain state (SSS) of tank metal structures under substructure settlement are discussed in many works [1-4]. They consider the limiting states of elements of the wall, bottom, stiffening rings, annular plates, roof, etc., arising in the case of non-axisymmetric effects caused by uneven settlement. However, to fully assess the technical condition of vertical steel tanks (VSTs), in case of the development of settlement, it is necessary to consider the effect of additional rigidity elements on the change in the SSS of metal structures [2]. Such elements are: a pipe header unit (figure 1), pipelines of the gas surge system, junction points of the shaft ladder with the wall of the VST.

The authors consider the effect of pipe header pipelines on the overall stress state of the structure during substructure settlement. The junction point of the pipe header with the tank wall is one of the most loaded areas. Adverse factors that affect the reliability of the pipe header junction point with the wall are: stress concentrators in welds, cyclic loads from loading-unloading operations, wall deflections at maximum product filling (up to 20 mm in a radial direction for a vertical steel tank 20000 m³ in capacity - VST-20000).
Especially dangerous is tank settlement which causes additional stresses in the metal structures, which, when combined with the operational ones, can subsequently lead to the appearance of limiting states in the metal [5]. In this case, when there are off-design loads from the non-axisymmetric effect of uneven settlement, additional investigation of the influence of the pipe header unit on the SSS of the elements of the structure is required.

Figure 1. Vertical steel tank 20000 m³ in capacity with a pipe header unit.

To obtain the numerical dependences of the settlement value on the stress state of the tank elements near the junction point of the wall with the pipe header, the authors propose to use numerical methods based on the finite element analysis. The software environment, ANSYS Workbench 14.5, allows performing calculations of non-axisymmetric deformation of a cylindrical shell considering the physical and geometric nonlinearity of the model [6-8].

2. Experimental part
The authors created a numerical model of VST-20000 with the junction point of the pipe header 700 mm (PH-700) in diameter. The junction point of PH-700 with the tank wall was built considering the real geometry of the metal structures: pipelines 700 mm in diameter with a 90° bend and reinforcing necks considering the design bend radius of the wall. The main technical and geometric characteristics of the tank according to the standard project: the diameter of the tank - 45600 mm, the height of the tank - 11920 mm, the thickness of the first wall belt - 13 mm, the thickness of the 2nd-8th belts - 11 mm, the height of the 1st-8th wall belts - 1490 mm, the width of the annular plate - 1200 mm, the thickness of the sheets of the central part of the bottom and the annular plate - 9 mm, the roof is fixed spherical, the height of the roof - 4000 mm, the thickness of the sheets of the roof covering - 6 mm. The diameter of the pipe header pipelines - 700 mm, the wall thickness of the pipelines - 11 mm, the thickness of the reinforcing neck - 12 mm, the distance between the supports - 2240 mm.

The contact task of connecting the pipeline to the wall and neck is solved considering the fixed welded joint based on the bonded contact. The boundary conditions for the interaction of the pipe
header pipeline with a sliding support are taken into account: the pipelines have complete freedom of movement in the horizontal plane and can also move vertically upward. At the same time, movement in the downward direction is prohibited, because the structure of the supports on which the pipe header pipelines are based does not involve settlement.

Figure 2 shows a design scheme of the pipe header unit of VST-20000. Settlement of the VST-20000 tank is modelled with the help of the displacement condition. The settlement value is given by a tabulated function that considers the limiting values of settlement from 1 to 50 mm. Preliminary estimates were made, on the basis of which the limits of the maximum settlement are determined. Thus, for settlement values < 1 mm, stress values do not exceed 150 MPa even with a fully filled VST. For settlement > 50 mm, stresses greater than 500 MPa occur in the VST wall even if there is no product.

To perform calculations, the model was divided into a finite element mesh. Pipelines were modelled using finite elements SHELL181, and reinforcing necks - using SOLID186. Elemental mesh refinement was 0.05 m, figure 3 shows a breakdown of the model elements into a finite element mesh. To obtain the numerical dependences of the effective equivalent stresses in the structures on the value of VST settlement, 8 cases of VST loading were considered: an emptied tank, a tank fully filled with oil with a filling level of 10.88 m, and 6 filling options by the value: 1.5; 3; 4.5; 6; 7.5; 9 m. The density of oil is assumed equal to 865 kg/m³. This approach makes it possible to evaluate the stress-strain state of the pipe header junction unit with the tank wall in various operational states and determine the maximum permissible value of the oil innage when the substructure settlement is detected.

3. Results and discussion
Figure 4 presents a model of the pipe header unit with the distribution of effective equivalent stresses in the metal structures. The case of a limiting state in the welded joint area of PH-700 pipelines with a wall for a 30-mm settlement is presented. The section with the greatest stresses is in the near-weld zone under the lower part of the branch pipe.

The design of the sliding support mounted on a separate substructure limits the movement of pipelines of the pipe header unit in the vertical direction downward, i.e. together with the settling VST. As a result, during the VST settlement, there occur deformations of the wall metal structures, reinforcing neck and the pipeline itself.
Figure 5 shows a model of the pipe header unit with the metalwork deformation distribution for a fully filled tank (oil filling height - 10.88 meters) with a 30-mm settlement. To assess the nature of displacements of the unit structures, the scale factor x30 for deformations is applied. The factor is used for the global affine coordinate system in the X, Y, Z planes. From figure 5 we can see that the VST-20000 shell wall experiences the greatest deformation from the off-design non-axisymmetric load caused by the substructure settlement. Based on the performed finite element calculations, we obtained dependences of the maximum effective equivalent stress acting in the metal structures on the value of VST-20000 settlement.

On the graphs (figure 6) the zone of approach of the limiting state in the metalwork is determined, namely, the yield strength of 09G2S steel $\sigma_{\text{yield}} = 325$ MPa is indicated. Thus, with a fully filled tank, the limiting state in the metalwork occurs at a 3-mm settlement; in the case of the emptied VST-20000, the limiting state occurs at a 30-mm settlement.
Figure 4. Equivalent stresses in the metal structures for an emptied tank with a 30-mm settlement.

Figure 5. Deformations of the metal structures of a fully filled tank (oil filling height - 10.88 meters) with a 30-mm settlement.
Figure 6. Dependences of the maximum effective equivalent stresses in the metal in the area of PH-700 connection with the wall on the value of VST-20000 settlement.

4. Conclusion

Based on the final element model of VST-20000 developed by the authors, modelling of the PH-700 oil pipe header unit was performed in [9-10]. The developed finite element model considers the geometric non-linearity of the structure, as well as the non-linear properties of the tank steel 09G2S.

In the non-linear setting of the problem, the ANSYS software package implementing the finite element method was used as a tool for obtaining parameters reflecting the actual SSS of the tank wall junction unit with the pipe header pipelines.

So, according to the results of calculations, new dependences of the maximum effective equivalent stresses in the metal in the area of PH-700 junction with the wall on the VST-20000 settlement value for an emptied tank and various cases of hydrostatic loading were obtained. These dependences characterize the actual stress-strain state of the structure. This conclusion is justified by the fact that the model used in the calculations has the maximum detailing of its elements and considers the geometric and physical non-linearity of the structure.

When settlement is 30 mm, the effective stresses reach 325 MPa (which corresponds to the yield strength of 09G2S steel) in all cases of loading, both in the most favourable with an emptied VST, and when it is filled with oil at different levels. The most dangerous case is settlement of a VST fully filled with oil, with the limiting state occurring at 3 mm, and when the settlement value exceeds 10 mm, the effective equivalent stresses reach 500 MPa, which leads to the occurrence of unacceptable plastic deformations.

The obtained dependences allow us to determine the areas of occurrence of limiting states, in accordance with which an operational decision is made about the need for repair or the possibility of continuing the tank operation. It confirms the practical significance of this study.

The calculated results of the stress-strain state of the tank metal structures with the settlement of its substructure and the obtained dependences can be used as a theoretical basis for the development of a
technique for assessing the technical state of the oil pipe header unit with the discovered settlement of the tank substructure.

Acknowledgments
The paper was prepared within the implementation of the basic part of the government task for the project No. 7.7858.2017/BP: "Development of the scientific principles of the techniques for determining the stress-strain state of the large-sized storage tanks during the differential settlement of the substructures and foundations".

References
[1] Zingoni A 2015 Liquid-containment shells of revolution: a review of recent studies on strength, stability and dynamics J. Thin-Walled Structures 87 102–114
[2] Godoy L A 2016 Buckling of vertical oil storage steel tanks: review of static buckling studies J. Thin-Walled Structures 103/1 1-21
[3] Morgun A and Met I 2009 Account of stresses redistribution in the process of investigation of stressed-strained state of joint functioning of the system basement-foundation construction. J. Sci. Works of Vinnytsia National Technical University 2 1-6
[4] Slepnev I V 1988 Stress-strain elastic-plastic state of the steel vertical cylindrical tanks with nonuniform settlement of bases (Moscow: Moscow Engineering and Construction Institute) p 225
[5] Boguchevskaya E M, Dimov I L and Dimov L A 2016 Determining tilt in tanks used to store oil and oil products during hydraulic testing and operation J. Soil Mechanics and Foundation Engineering 53/1 35-38
[6] Bruyaka V A, Fokin V G, Soldusova E A, Glazunova N A and Adeyanov I E 2010 Engineering Analysis in ANSYS Workbench (Samara: Samara State Technical University) p 271
[7] Beloborodov A V 2005 Evaluation of Finite Element Model Construction Quality in ANSYS J. Computer engineering analysis 1 78-81
[8] Korobkov G E, Zaripov R M and Shammasov I A 2009 Numerical modeling of the stress-strain state and stability of pipelines and tanks in complicated operating conditions (St. Petersburg: Nedra) p 410
[9] Tarasenko A, Gruchenkova A and Chepur P 2016 Joint deformation of metal structures in the tank and gas equalizing system while base settlement progressing. J. Proc. Engineering 165 1125-1131
[10] Tarasenko A A, Konovalov P A, Zekhniev F F, Chepur P V and Tarasenko D A 2017 Effects of nonuniform settlement of the outer bottom perimeter of a large tank on its stress-strain state J. Soil Mechanics and Foundation Engineering 53/6 405-411