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IMPACT ASSESSMENT OF METAL CORROSION ON FUEL RESERVOIR CARRYING CAPACITY

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Abstrakt. To prevent the large-scale contamination at the Vernadsky Station the development of the automated early-warning system of the leak fuel possibility is predicted in the State Target Scientific-Technical Research Program in the Antarctic for 2011-2020. An important component of the system is a subsystem of control and visualization the tensioned-deformed condition of the 200 m^3 reservoir construction providing the lack of the necessary technical documentation and of data by the current thicknesses both walls and welds of reservoir.
The impact of corrosion from diesel fuel was studied on the carrying capacity of the conditional reservoir model (CRM). Using the finite elements method, which is implemented in software complex NASTRAN, the mathematical modeling was carried out of the CRM nonlinear behavior considering thinning of its wall in the system with protective capacity under the static loads action. Six options of the walls thinning were accepted in the various reservoir zones in 0.25, 0.5, 0.75, 1.0, 1.25, 1.5 mm.
Nonlinear calculations of the CRM both tension-deformed state and stability were carried out using the modified method of the incremental Newton-Raphson load. Studies have shown that thinning of the walls on 1.5 mm reduces the stock stability approximately in 30%, with the maximum intensity for all options of wall thinning is observed in the lower zone of the CRM with the protective capacity.
The obtained results can be immediately applied for analysis of the carrying capacity of the real reservoir construction after obtaining of the quantitative characteristics of the walls reservoir thicknesses and after the technical documentation development for the real reservoir construction.

Key words: metal corrosion, quantification of carrying capacity of fuel reservoir.

Оцінка впливу корозії металу на несучу спроможність паливного резервуара.
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Реферат. Для запобігання забрудненню навколишнього середовища на антарктичній станції «Академік Вернадський» у Державній цільовій науково-технічній програмі досліджень України в Антарктиці на 2011−2020 рр. передбачена розробка автоматизованої системи раннього попередження можливості витоку пального. Важливою складовою зазначеної системи є підсистема контролю і візуалізації напружено-деформованого стану конструкції резервуару ємністю 200 м^3 в умовах нестачі необхідної технічної документації та даних про поточні товщини стінок і зварних швів резервуару.
В роботі досліджується вплив корозії металу на несучу спроможність умовної моделі резервуару (УМР) ємністю 200 м^3 для дизельного пального. За допомогою методу скінченних елементів, який реалізований в програмному комплексі NASTRAN, виконано математичне моделювання нелінійної поведінки УМР з урахуванням потоншення його стінки в системі із захисною ємністю при дії статичних навантажень. Прийнято шість варіантів потоншення стінки під дією коррозії у вигляді зменшення товщини різних поясів резервуара на

0.25, 0.5, 0.75, 1.0, 1.25, 1.5 мм. Виконані нелінійні розрахунки напружено-деформованого стану і стійкості УМР за допомогою модифікованого методу покрокового навантаження Ньютона-Рафсона. Дослідження показали, що потоншення стінки на 1.5 мм зменшує запас стійкості приблизно на 30%, при цьому максимальні напруження для всіх варіантів потоншення стінки спостерігаються в нижньому поясі УМР з захисною ємністю. Одержані результати можна негайно застосувати для аналізу несучої спроможності реальної конструкції після одержання кількісних характеристик товщин стінок і розробки технічної документації на реальну конструкцію резервуару.

1. Introduction

Destruction of oil tanks and pipelines structures creates the major threats of environmental disasters. At the Antarctic Stations to prevent such accidents the necessary measures are regulated in the Antarctic Treaty System [1]. In pursuance of this Protocol National Antarctic Scientific Centre (NASC), National Technical University of Ukraine "Kyiv Polytechnic Institute" (NTUU "KPI"), Kyiv National University of Construction and Architecture (KNUCA) developed additional measures [2] to ensure the environment protection at the Ukrainian Vernadsky Station from specific threats from the new reservoir of the 200 m^3 diesel fuel capacity.

In particular, the presence of such threats was fixed [3]:

• Lack of the necessary technical documentation for the real reservoir construction, therefore, lack of the real carrying capacity calculation for the real reservoir construction;

• Lack of the quantitative characteristics of the reservoir welds defects the and the lack of the thicknesses quantitative characteristics of the reservoir joints and walls which are necessary for calculation of the carrying capacity of the reservoir real construction.

In turn, a special threat for reservoir welds and walls is the metal corrosion due to the aggressive influence of the diesel fuel which further reduces the reservoir carrying capacity.

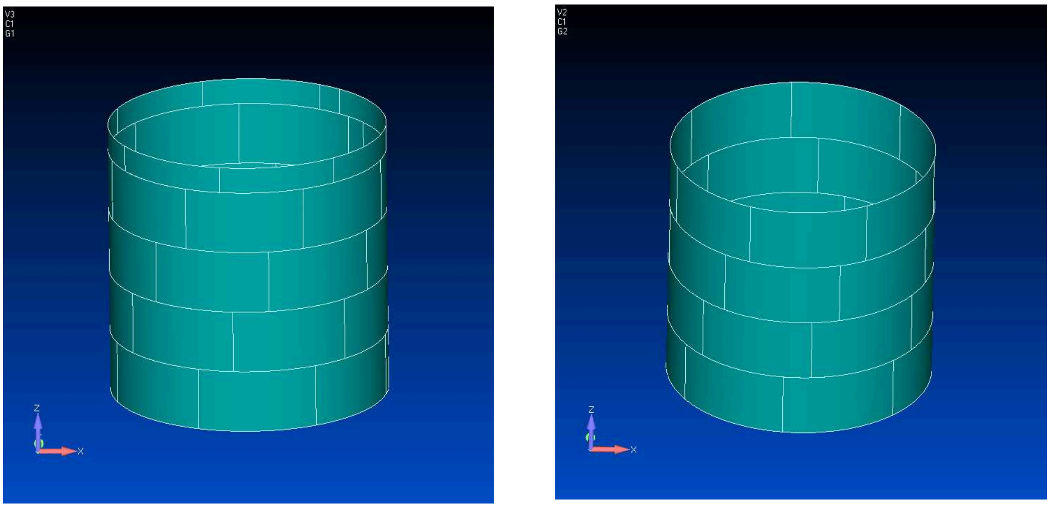
Given the above-mentioned, the specialists team of NASC, NTUU «KPI», KNUCA has proposed Project for the development of the automated early warning system of the fuel leakage possibility from the new reservoir, which was included in the State Target Scientific-Technical Program of Research in Antarctica for 2011—2020 in the field «New technologies. «

The Project was supported on the Symposium of Annual (2012) Meeting of the Council of Managers of National Antarctic Programs (COMNAP) [4] and was included in the Strategic Plan COMNAP on 2013 — 2015. The important component of the proposed Project is the subsystem of the regular monitoring and visualization of the carrying capacity of the real reservoir construction. The aim of this study is the evaluation of the corrosion impact on the carrying capacity of the conditional reservoir construction (CRC) to determine the conditions of the possible loss of the reservoir mechanical stability.

2. Mathematical modeling of the CRC carrying capacity

The fuel reservoir with the protective capacity is the complex spatial thin-walled shell construction. The construction carrying capacity is ensured by the compliance with conditions of its strength and stability. Practice proves more dangerous for thin-walled structures are the non-fulfillment of the stability conditions. Construction stability is considered secured if buckling load (critical load) is greater than the calculated limit load which is calculated according to [12]. The main influencing factor is the walls geometric imperfections which have an influence on the decline of the critical load for the thin cylindrical shells [5, 6, 7, 8].

The software complex of finite-element analysis (MCE) MSC.NASTRAN [9]] was used to investigate the stability of the fuel reservoir system with spare capacity. Diesel fuel reservoir is a metal cylinder with a height of 5.96 m and with a diameter of 6.63 meters, which is inside a protective metal cylindrical shell by a height of 6.58 m and by a diameter of 6.96 m. The walls of the shells ware welded from rolled sheets by 5 mm thickness. In this paper the finite-element model of the reservoir with the protective capacity is formed based on the assumption for welds according to the recommendations of the complex NASTRAN developers. The shells walls are modeled in the zones forms, consisting the surfaces (bodies), whose dimensions are corresponded to rolled sheets (Fig. 1).



a) protective capacity b) fuel reservoir

Fig. 1. Modeling of shall walls.

Each surface is presented by the set of flat rectangular finite elements with six degrees of freedom in the node type Plate (Fig. 2).

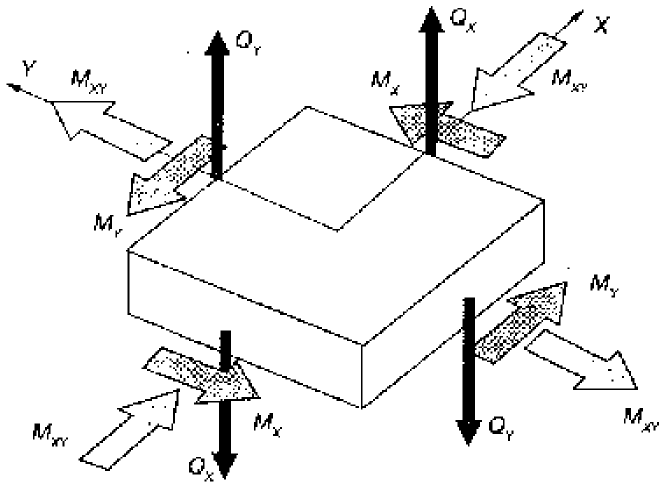


Fig. 2. The finite element of the Plate type.

The finite-element model of the fuel reservoir construction with protective capacity is shown in Fig. 3. The circumference of the inner shell is divided into 90 parts, by a height — into 20; Outdoor: by a circle — into 72 parts, by a height — into 22. Tubulures (pipes) for pumping and draining fuel have a diameter of 3 inches and a length of 0.16 m and are modeled by two types of Tube rod elements. The four-corners flat inner shell finite elements are replaced with the three-corners elements in the tubulures mounting places. The quantity of flat two-dimensional finite elements of the full model is 3548, the knots quantity — 3392.

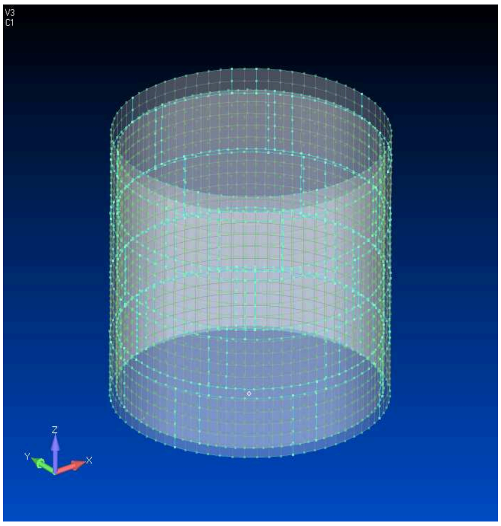


Fig. 3. Finite-element model of two shells set.

According to the existing technical documentation [3] shells are made from the material St3ps2 which physical characteristics are given in the Table H.1 [10].

Boundary conditions are adopted in accordance with: translational movement along the radius are limited in the internal nodes of the reservoir lower edge, the rotational movement are limited around the radius and the tangent (modeling placing the reservoir on oak girders). The nodes of the reservoir lower edge of the outside reservoir are rigidly mounted. On the nodes of upper edges of the two shells the restrictions are put by the range and by generators (simulation of movement restriction by reservoir roofs).

The main loads on the reservoir with diesel fuel are: the fuel weight load, the roofing and technological equipment. According to [11] the fuel weight is the long-term variable loads. It is modeled in the form of a triangle-divided lateral pressure on the inner surface of the reservoir, which the maximum threshold value is 70257.7 Pa by the fully filled reservoir. The load of the reservoir roof and equipment weights relates to constant load and is modeled in the form of concentrated forces applied to the respective nodes of the shell upper edge. The limiting estimated load of the roof weight on the reservoir one node is 624.86 H, the maximum value of the equipment weight is 259.56 H.

3. Modeling the corrosion impact on the reservoir wall thinning

The corrosion of the reservoir walls metal is considered through the modeling of a conditional reduce its thickness to 0.25, 0.5, 0.75, 1.0, 1.25, 1.5 mm. The six options (schemes) are accepted of the rolling sheets thinning of the reservoir walls zones which are represented in Fig. 4.

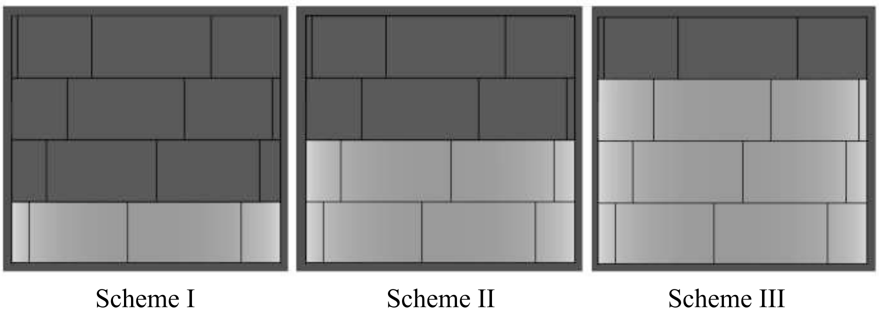


Fig. 4. Thinning options of fuel reservoir walls (Scheme I, Scheme II, Scheme III).

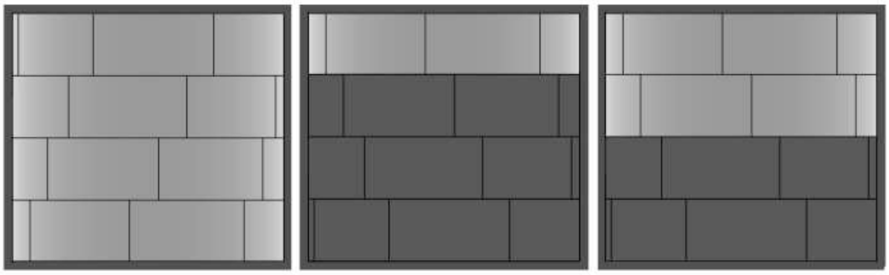


Fig. 4. Thinning options of fuel reservoir walls (Scheme IV, Scheme V, Scheme VI).

The nonlinear study of the fuel reservoir behavior, its tensioned-deformed state and stability under the action of static loads are performed based on the finite-element model structure (Fig. 3) under various schemes thinning (Fig. 4) and varying the wall thickness of the fuel reservoir.

4. Exploration methods of the fuel reservoir carrying capacity

According to regulations [10, 11] the constructions should to be calculated by the method of limiting states, the main provisions of which are aimed at ensuring of the design reliability and during the construction and operation. Construction reliability is provided when the estimated efforts, tensions, deformations and displacements does not exceed the relevant thresholds laid which are down by the structural design rules. In the paper carrying capacity of the fuel reservoir from the static load is investigated using the procedure of solving nonlinear statics task by the Nonlinear Static, which is implemented in the NASTRAN software complex.

The equations of the structure equilibrium are formed on the basis of possible movements, and are solved using the modified method of the Newton-Raphson's incremental load. According to recommendations [12] threshold calculated resistance of steel St3ps2 is determined taking into account the characteristic impedance for liquid limit of 245 MPa, reliability coefficients for the material of 1.05 and working conditions, which is 0.7 for the first zone and 0.8 for others zones. In the calculation the allowable stress in model cells is adopted 163 MPa and 187 MPa respectively for the first and the others reservoir belts. As a calculation result the construction reaction to external influence is presented as a model of moving the same fields of model nodes, transverse forces, membrane stresses, bending moments and equivalent tensions in the construction elements.

To study of the structures stability the procedure Nonlinear Static is used in software complex NASTRAN. It provide an opportunity to analyze the construction tensioned-deformed state at each step load mode to determine the critical load value and to calculate the stability factor, as the ratio of the critical load to the limiting calculated value.

The impact of the fuel reservoir wall thinning to its strength is evaluated by means of the obtained deformation values and equivalent tensions in the model elements. The impact of the fuel reservoir wall thinning to the reservoir stability is evaluated by means of the safety factor of stability. The fuel reservoir strength would be considered as secured if the resulting maximum tension in the model elements does not exceed the allowable value, and the reservoir stability — if the stability factor is more than the required value of the metal constructions security characteristic, which is 3 and corresponds to the destruction probability 3*10-5 [11].

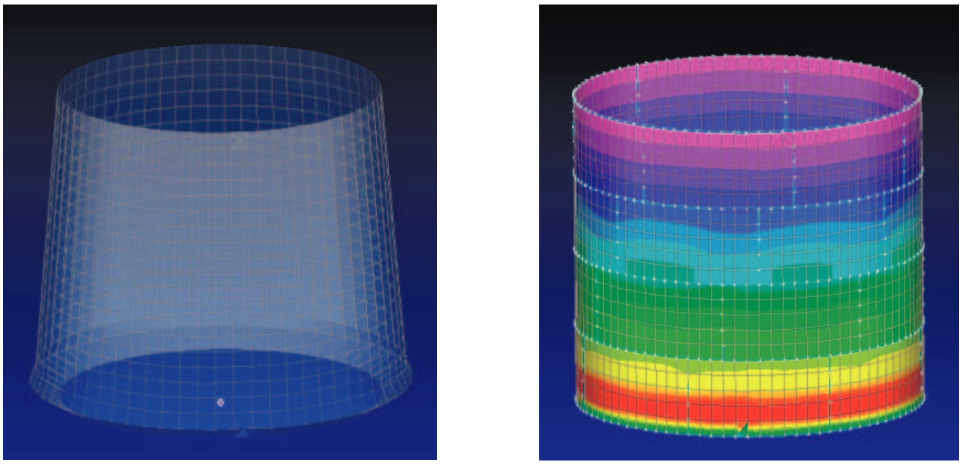
5. The study results

Assessing the impact of corrosion on the carrying capacity of the fuel reservoir is carried out by comparing its states both without and with considering the wall thinning. Table 1 shows the results of the study reservoir tensioned-deformed state without the wall thinning under the fuel weight action.

Table 1

Characteristics of the reservoir state	The fuel load as a part of the reservoir volume			
	1/4	1/2	3/4	4/4
Tension, MPa	12,1723	26,5936	41,1051	55,7664
Deformation, mm	0,207	0,476	0,728	0,978

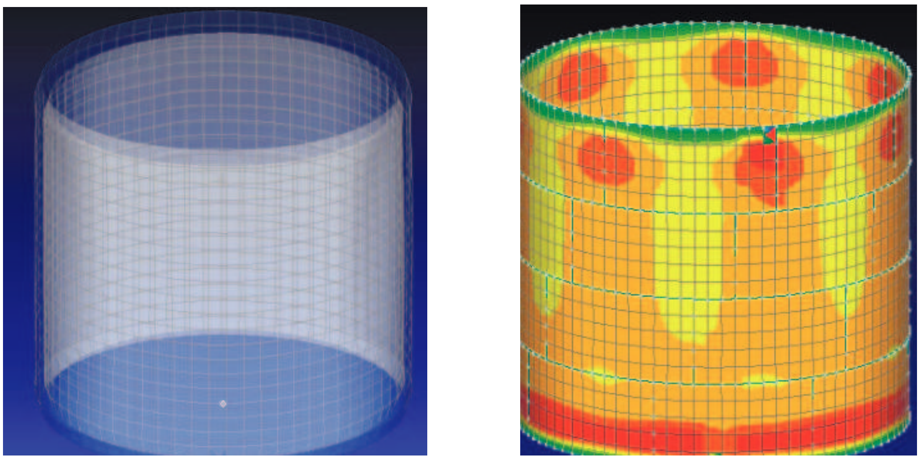
Table 1 shows that the maximum tensions and deformations do not exceed the permissible values and the reservoir strength is ensured. Fig. 5 shows the reservoir tensioned-deformed state under the full reservoir filling.



a) deformations b) tensions

Fig. 5. Reservoir tensioned-deformed state under the fuel weight action.

For four variants of the reservoir filling the maximum tensions and deformations were observed in the wall cells near its lower edge. In the reservoir wall near the pipe for draining fuel is a tensions concentration. The load action of the roof and equipment weight on the reservoir tensioned-deformed state is shown in Fig. 6. The tension maximum 0.603 MPa and deformation maximum 0.016 mm were observed in the cell wall of the lower reservoir zone. There is the tension concentration in the reservoir wall at the fill pipe for fuel.

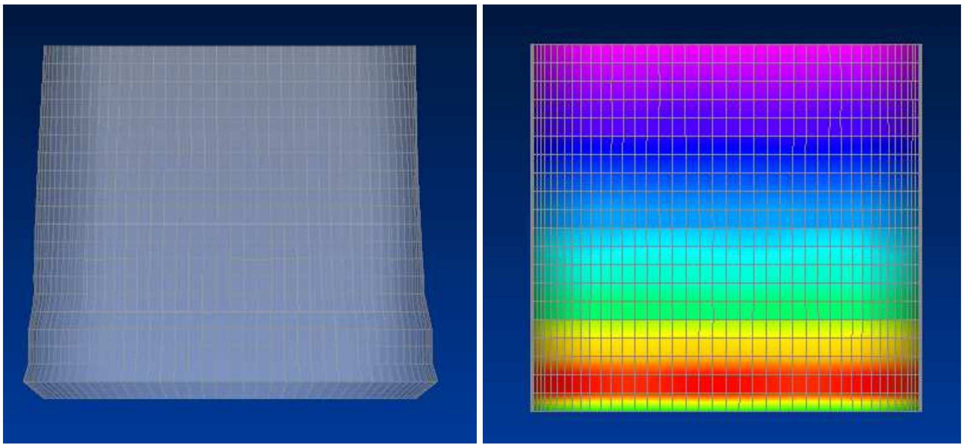


a) deformations b) tensions

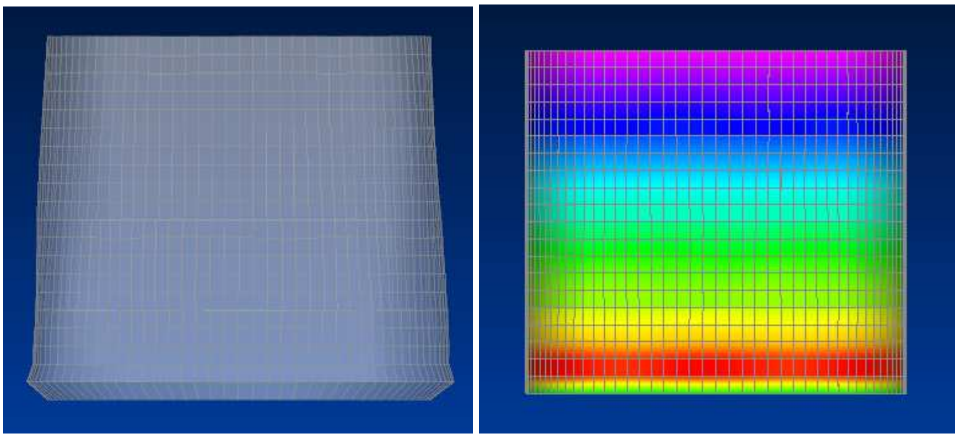
Fig. 6. Reservoir tensioned-deformed state under the roof and equipment weight action.

The obtained results indicate that the surface pressure of the fuel weight on the reservoir wall causes the tension in the model elements much larger than the axial load of the roof and equipment weight. Therefore, the study of influence of the reservoir wall thinning on its carrying capacity was considered only the effect of the fuel weight load under the completely filling.

The studies of nonlinear reservoir behavior were made on the basis of six schemes of the wall thinning (Fig. 4) and the thickness reduction of rolling sheets on $\Delta t = (0{,}25 \div 1{,}5)$ mm. The studies showed that the maximum tensions and deformations by buckling were observed in the fuel reservoir lower zone under all versions of the wall thinning. Fig. 7 shows the reservoir tensioned-deformed state by the wall thinning on 1.5 mm in accordance with schemes I and IV under the stability loss.



a) scheme I



b) scheme II

Fig. 7. Reservoir tensioned-deformed state by the stability loss (Δt =1,5 mm).

During determining of the critical load (q_{kr}) the condition of wall strength was checked, that is the tensions maximum must not exceed the allowable tension 163 MPa in the first zone and 187 MPa in other zones of the reservoir wall.

The condition of the reservoir wall stiffness was checked: the maximum deformations must not exceed the permissible values. Fig. 8 presents the curve of the reservoir lower zone node moving by the wall thinning 1.5 mm (Scheme IV) from the stepwise applying load (q), which was estimated in four times greater than the calculated value limit of the operating load (qp). To study the reservoir behavior the modified method of Newton-Raphson was used. The nonlinearity is observed at the beginning of the load application. Loss of stability took place under load, which is critical and in 2.454 times more than the limit calculated value.

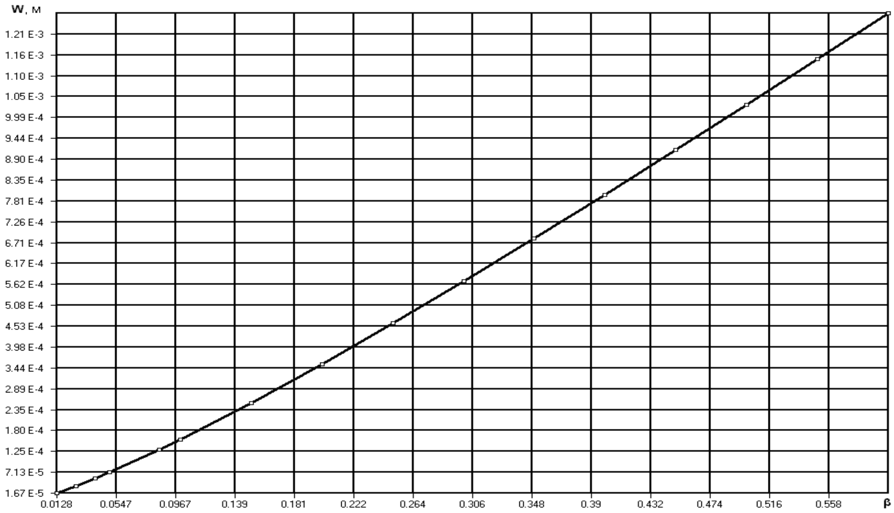
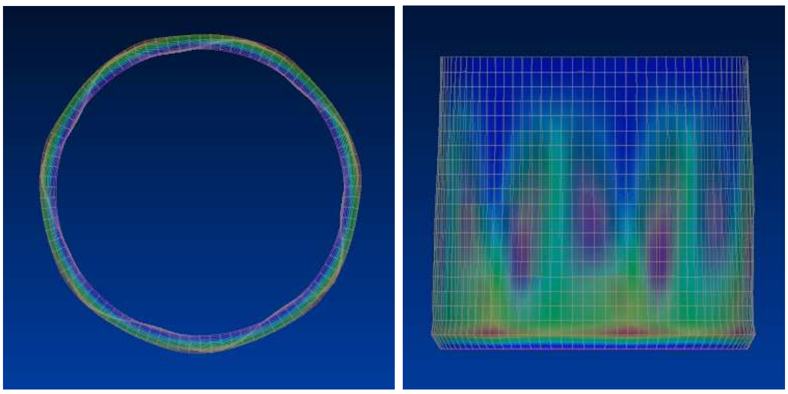
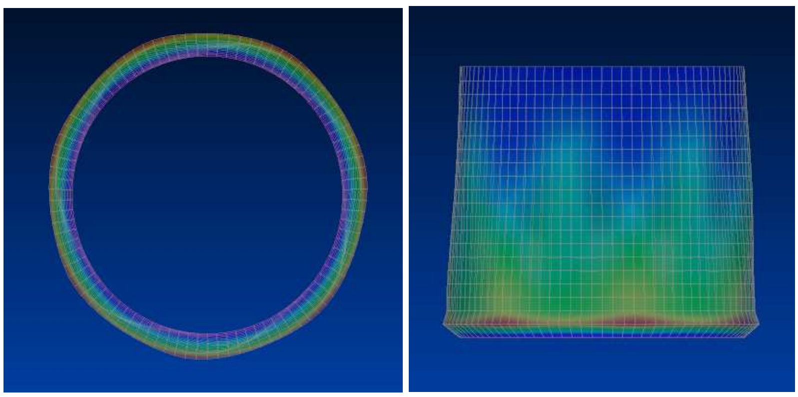


Fig. 8. The stepwise load curve of the fuel reservoir.

The fuel reservoir deformation shape with the same movements under the stepwise loading is shown in Fig. 9.



a) $q = 0{,}52\ q_p$



б) $q = 1{,}62\ q_p$

Fig. 9. Reservoir deformation form under stepwise loading.

The maximum displacements were equal to 3.4 mm and were observed in the lower zone of the reservoir wall at q_{kr} = 2.454 q_p.Tables 2 and 3 show the safety factors of the fuel reservoir stability in the system with the defensive capacity and without it.

Table 2

Scheme number	Factor stability					
	Fuel reservoir wall thinning Δt, mm					
	0,25	0,5	0,75	1,0	1,25	1,5
I	2,8014	2,655	2,4944	2,3395	2,1863	2,0361
II	2,8011	2,6550	2,4941	2,3382	2,1851	2,0354
III	2,8009	2,6548	2,4932	2,3374	2,1849	2,0350
IV	2,8007	2,6546	2,4929	2,3368	2,1847	2,0342
V	2,8934	2,8934	2,8934	2,8934	2,8934	2,8934
VI	2,89324	2,8922	2,89320	2,89318	2,89313	2,89307

Table 3

Scheme number	Factor stability					
	Fuel reservoir wall thinning Δt, mm					
	0,25	0,5	0,75	1,0	1,25	1,5
I	3,3595	3,1781	2,9970	2,8166	2,6367	2,4564
II	3,3589	3,1773	2,9962	2,8154	2,6352	2,4551
III	3,3588	3,1772	2,9961	2,8153	2,6351	2,4550
IV	3,3587	3,1771	2,9960	2,8152	2,6348	2,4549
V	3,3865	3,3865	3,3865	3,3865	3,3865	3,3865
VI	3,3865	3,3864	3,3863	3,3862	3,3861	3,3859

The above tables show that for the first four schemes, where there is thinning of the first zone, factor of stability is reduced with increasing Δt. Thus, while the wall thickness reducing is 1.5 mm stability safety factor was decreased by about 30%. When thinning of the upper zone (Scheme V) impact of corrosion on resistance is not observed. Impact of the thickness reducing of the top two reservoir zones (Scheme VI) on the resistance is insignificant. Fig. 10 shows the dependence of the stability safety factor from the reservoir wall thinning for scheme IV. Curve 1 corresponds to the behavior of the reservoir in the system with protective capacity, curve 2 — without connection with the protective capacity.

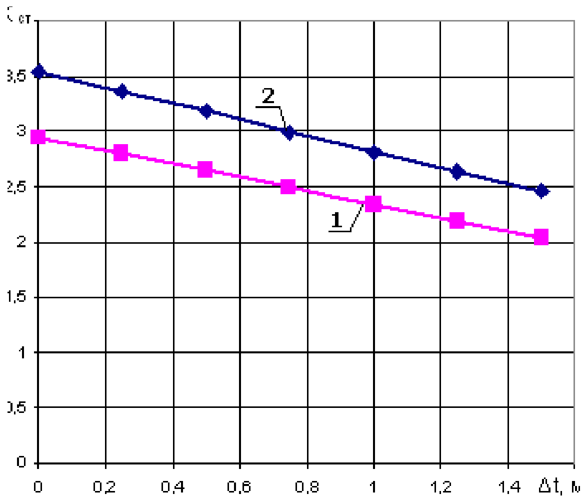


Fig. 10. Dependence of the safety stability factor from the wall thinning.

The obtained results showed the reservoir state is more dangerous in the system with protective capacity due to the presence of the two shells joining elements. Therefore, the required reserve of the fuel reservoir stability is not provided (< 3) [11].

6. Conclusion

The carried out studies confirmed the significant impact of corrosion on carrying capacity of the fuel reservoir. When thinning of the reservoir walls is 30-35% or more, the reservoir condition should be considered as dangerous for the further operation.

In view of the obtained results should be:

• to reduce operational load of the fuel weight on the reservoir;
• to introduce regular diagnosis of joints and walls of the reservoir and protective capacity;
• to develop the technical documentation of real reservoir construction.

In the case of these measures implementation this study results can be immediately used to assess the carrying capacity of the real reservoir construction and to develop solutions for the further reservoir operation at the Antarctic Station.

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