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NUMERICAL ASSESSMENT OF SEISMIC STRENGTHENING OF A FULLY FILLED VERTICAL STEEL OIL STORAGE TANK USING CIRCUMFERENTIAL STIFFENING RIBS

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Abstract: This study presents technical solutions aimed at reducing the seismic vulnerability of existing storage tanks. Scientific and engineering proposals are developed to enhance the seismic resistance of the tank, and structural strengthening measures are formulated based on numerical analyses performed using the LIRA-SOFT 10.12 software package.

Based on the obtained results, effective engineering solutions are proposed to mitigate seismic impacts and improve the overall structural safety and reliability of the tank.

Keywords: LIRA-SOFT 10.12 software, seismic loads, equivalent stress, stiffening ribs, loading conditions, stiffness parameters, dynamic effects.

Introduction: Ensuring the seismic resistance and stability of existing storage tanks at oil product facilities remains one of the most critical challenges in modern structural engineering. Extensive research efforts are currently focused on improving the local stability and strength characteristics of storage tank structures. In particular, these studies highlight the necessity of enhancing the performance of metal storage tanks through the application of stiffening ribs.

In addition, the regulatory framework and policy measures adopted by Shavkat Mirziyoyev concerning seismic safety play a significant role in improving structural reliability in seismically active regions of the country.

For the present study, an existing storage tank was selected whose geometric and structural parameters exceed the permissible limits specified in Table 3 of Appendix 3 of SHNQ 2.03.05-23. A detailed recalculation was carried out under the condition of 100% filling using the LIRA-SOFT 10.12 software package in order to develop appropriate engineering solutions.

Within the numerical analysis, four types of loading were considered: the self-weight of the structure, hydrostatic pressure of the stored liquid, and dynamic seismic loads applied along the X and Y directions based on accelerograms. Preselected accelerograms were adopted to represent seismic excitation during the simulation process.

During the computational study, various configurations of stiffening ribs were introduced into the tank wall, and the resulting equivalent stresses due to deformation were evaluated. These values were then compared with the stress state of the tank without stiffening elements. The results demonstrate that the inclusion of stiffening ribs leads to a substantial reduction in equivalent stresses, ensuring compliance with the relevant regulatory requirements.

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Based on the analysis outcomes, detailed structural drawings of the optimal stiffening rib arrangements were developed and are presented in Appendix 1.

Table 1

Technical characteristics of the tank adopted for calculation			
№	Designation	Quantity	Unit of measurement
1	Height	12	m
2	Diameter	10.3	m
3	Wall thickness	4	mm
4	Bottom plate	3	mm
5	Roof	3	mm
6	Transverse stiffening rib	6	mm
7	Volume	1000	m^3
8	Design yield strength of steel, Ry	245	MPa

The analysis is carried out for the following loads:

Load Case 1 – Static load corresponding to the self-weight of the structure, classified as a permanent action.
Load Case 2 – Static load representing the hydrostatic pressure of the stored liquid acting on the tank bottom and walls, also treated as a permanent action.
Load Case 3 – Dynamic load induced by an accelerogram applied along the X-axis, considered as a seismic action.
Load Case 4 – Dynamic load induced by an accelerogram applied along the Y-axis, likewise considered as a seismic action.

Material classification

Table 3

T/r	Name	Color	Mechanical properties
2	Steel (C245)		Steel grade: C245 Density: ρ=7.85(t/m^3); Elastic modulus: E=2.1006E+06(kg/cm²); Shear modulus: G=8.0558E+05(kg/cm²); Poisson's ratio: ν=0.3;

CHARACTERISTICS OF DYNAMIC LOAD ANALYSIS

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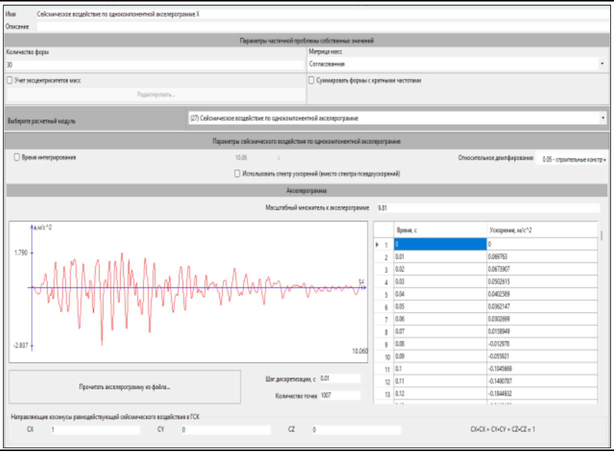
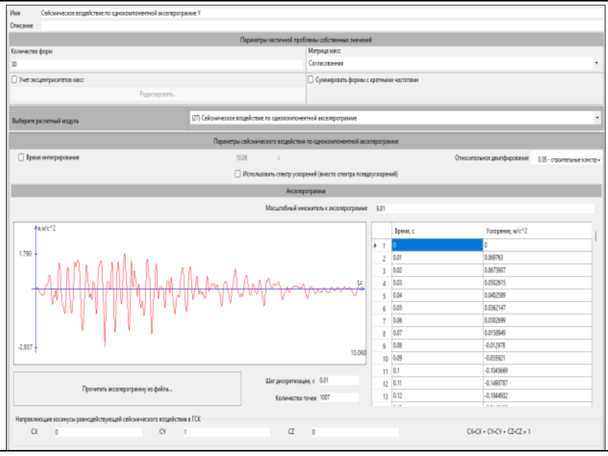
	

Figure 1a. Dynamic action in the X-axis direction	Figure 1b. Dynamic action in the Y-axis direction

The storage tank considered in this study is a vertical cylindrical metal structure intended for the storage of oil products, and its geometric and structural parameters were adopted in accordance with the initial technical documentation. The tank shell is made of welded steel plates, with a height (H) of **12 m** and an internal diameter of **10.3 m**. The shell wall thickness is **4 mm** over the entire height, while the bottom plate and the roof are made of steel with thicknesses of **3 mm** and **3 mm**, respectively.

To enhance the strength of the tank wall, **transverse stiffening ribs with a thickness of 6 mm** were installed. These ribs reduce the stresses induced in the tank wall by seismic loads and improve the overall stability of the structure (Figures **2a–2d**).

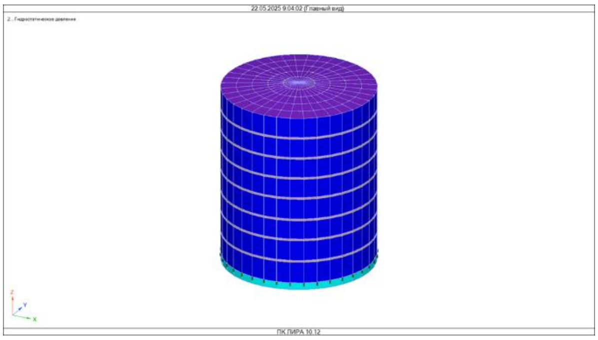


Figure 2a. General view of the computational model of the tank

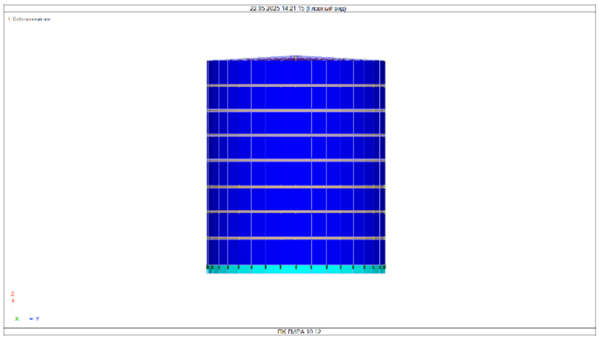
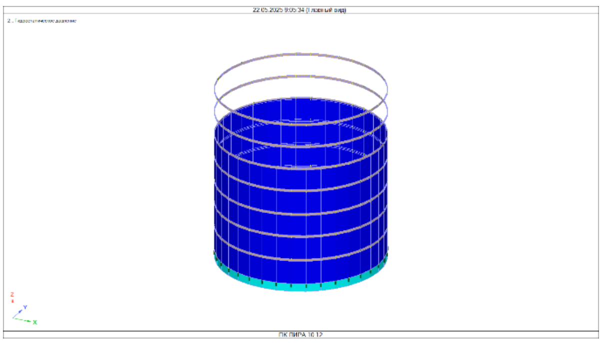


Figure 2b. General view of the computational model of the tank



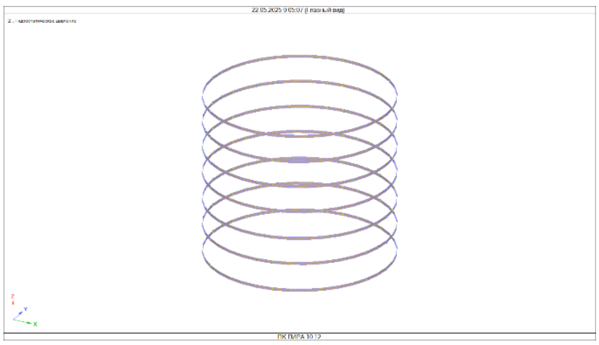


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Figure 2c. General view of the stiffening ribs in the computational model of the tank

Figure 2d. General view of the stiffening ribs in the computational model of the tank

For the considered vertical cylindrical steel storage tank, the distribution of equivalent stresses (σ_E) in the wall plates was evaluated under different operational conditions, specifically at liquid filling levels of 50%, 75%, and 100% of the tank capacity. The results revealed a pronounced variation in stress magnitudes along the height of the tank wall, particularly within the lower, middle, and upper zones.

The level of liquid filling has a direct influence on both hydrostatic and hydrodynamic pressures acting on the tank structure. At a 50% filling level, the equivalent stresses are predominantly concentrated in the मध्य region of the wall. In contrast, at 75% and especially at full (100%) filling, the maximum stress values are observed in the нижний zone. This pattern is attributed to the linear increase of hydrostatic pressure with depth, as well as to the dynamic interaction between the tank wall and the impulsive component of the liquid during seismic excitation.

The application of different analytical and numerical approaches for cylindrical storage tanks, including finite element modeling using LIRA-SOFT, enabled a detailed assessment of the actual structural response under loading conditions. These methods facilitated a comprehensive investigation of local wall deformations, the reinforcing effect of stiffening ribs, the interaction between the bottom and wall elements, and the influence of additional dynamic pressures arising during seismic action.

The results of the structural analysis are fully presented and systematically illustrated in the “Evaluation Graph of the Limit State of the Tank Structure.” This graph clearly demonstrates the distribution of stresses along the height, identifies the locations of maximum σ_E values, highlights the effectiveness of stiffening ribs, and indicates the degree to which the structure approaches its limit state. Such analyses are of considerable practical importance for the development of effective seismic safety measures for storage tank structures.

CALCULATION RESULTS OF THE TANK STRUCTURE

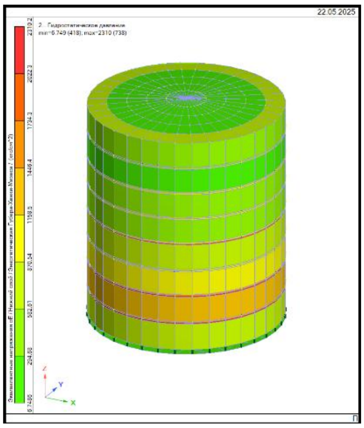


Figure 3a. Equivalent stress σ_E in the lower zone [Hydrostatic pressure], kgf/cm²
(100% liquid-filled condition)

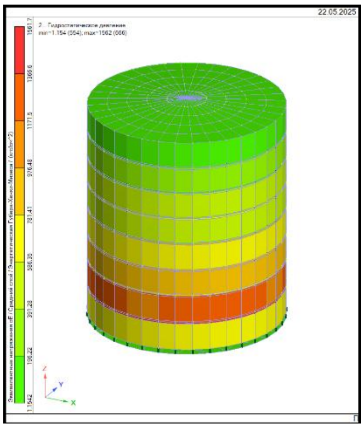
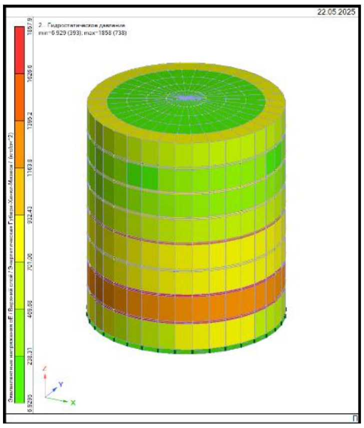


Figure 3b. Equivalent stress σ_E in the middle zone [Hydrostatic pressure], kgf/cm²
(100% liquid-filled condition)



igure 3c. Equivalent stress σ_E in the upper zone [Hydrostatic pressure], kgf/cm²
(100% liquid-filled condition)

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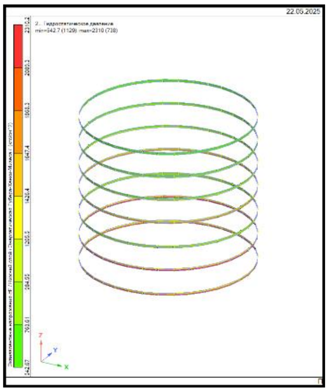
Figure 3d. Equivalent stress σ_E in the lower zone [Hydrostatic pressure] for the strengthened tank belts, kgf/cm²

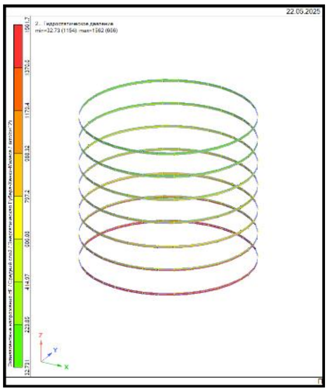
Figure 3e. Equivalent stress σ_E in the lower zone [Hydrostatic pressure] for the strengthened tank belts, kgf/cm²

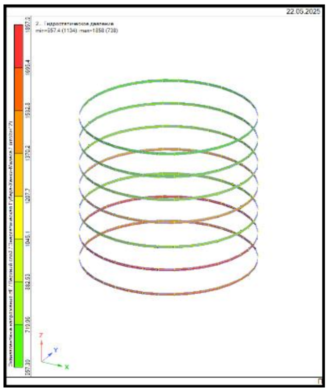
Figure 3f. Equivalent stress σ_E in the lower zone [Hydrostatic pressure] for the strengthened tank belts, kgf/cm²

LIMIT STATE ASSESSMENT OF THE TANK STRUCTURE

Table 4

Analysis of the calculation results of the tank structure				
Liquid filling level	100%	in the walls	in the belts	Ry
Lower layer	σ_E	2320.0	2320.0	2450
Middle layer	σ_E	1551.5	1551.5	2450
Upper layer	σ_E	1858.0	1858.0	2450

Conclusion:

In accordance with Clause 12.4 of Resolution No. PQ-161, technical investigations were conducted on vertical steel storage tank No. 38 located at the facility of Farg'ona Neft Bazasi LLC, with the objective of developing engineering solutions to mitigate the seismic risk identified in existing tanks.

Preliminary assessments, performed במסגרת the implementation of Clause 12.3 of the same Resolution, revealed that the equivalent stress values in the examined tank exceed the allowable limits established by the current regulatory standards, including SHNQ 2.02.01-19 “Foundations of Buildings and Structures” and SHNQ 2.03.05-23 “Steel Structures. Design Requirements.”

Based on these findings and in accordance with Clause 12.4 of the Resolution, the development of a scientific and technical solution aimed at enhancing the seismic resistance of the storage tank was deemed necessary. As part of this process, recalculation analyses were carried out using the LIRA-SOFT 10.12 software package.

The analysis results formed the basis for proposing strengthening measures involving the installation of seven circumferential (transverse) stiffening ribs fabricated from steel plates.

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These ribs are arranged along the height of the tank at intervals of 1.5 m, as illustrated in Appendix 1, with the aim of improving the overall strength and seismic performance of the tank wall.

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