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Seismic Resistance Assessment of a Cylindrical Steel Oil Storage Tank under Different Liquid Filling Levels: A Case Study of Fergana City

Shoxrux Davlyatov[1]
Ayubxon Nazirov [2]
Umirzakov Zukhriddin[3]
[1] Fergana state technical university, Fergana, Republic of Uzbekistan;
[2] Fergana state technical university, Fergana, Republic of Uzbekistan;
[3] Fergana state technical university, Fergana, Republic of Uzbekistan

Annotation:
This article presents the assessment of the seismic resistance level of reservoirs used in the oil and oil-gas industry and examines the conditions required to maintain their structural stability under dynamic loading. The study includes the analysis of existing operating reservoirs using the LIRA-SAPR 10.12 software package, with particular emphasis on the evaluation of equivalent stress results. Furthermore, the distribution of equivalent stresses occurring in the plates of a cylindrical steel reservoir structure was analyzed based on calculation results obtained for liquid filling levels of 50%, 75%, and 100%.
Keywords:
Steel reservoir; Seismic resistance; Structural stability; Equivalent stress; Deformation; Strength; Static Pressure.

Introduction

Due to the fact that more than 78% of the territory of our republic is located in seismically active zones, consideration of seismic loads in the design of buildings and structures, as well as ensuring the seismic resistance of hazardous industrial facilities and public safety, remains one of the most pressing challenges.

Worldwide, including in our republic, the prediction and prevention of earthquakes still remain unresolved issues. Therefore, ensuring the seismic safety of territories through improving the earthquake resistance of existing reservoirs used for the storage of oil and petroleum products is always of significant importance.

According to Clause 7 of the Resolution PQ-158 of the President of the Republic of Uzbekistan dated May 16, 2023, entitled “On Additional Measures for Further Improving the System of Ensuring Seismic Safety of the Population and Territory of the Republic of Uzbekistan,” provisions were established for the classification of buildings and structures according to their seismic vulnerability, as well as for conducting instrumental and technical inspections (microdynamic tests) using modern specialized equipment and software, and coordinating activities aimed at improving their seismic resistance.

Furthermore, measures aimed at enhancing the seismic resistance of buildings and structures and improving seismic risk monitoring activities were defined in Appendix 13, Clause 2 of the Resolution PQ-161 of the President of the Republic of Uzbekistan dated April 17, 2024.

Despite the continuous development of the construction industry, earthquakes still remain one of the most dangerous natural disasters, causing numerous severe accidents and catastrophic consequences. Among the structures most vulnerable during earthquakes are vertical storage tanks used for storing fuel products, which may experience significant damage and, in some cases, catastrophic failure. The ongoing development of the oil and gas industry has led to the construction of a large number of storage reservoirs even in seismically hazardous regions.

At present, there are no comprehensive conclusions or monitoring observations regarding the seismic resistance of existing reservoirs at hazardous industrial facilities under seismic impacts.

The main objective of this article is to conduct research on the assessment of the seismic resistance of reservoirs in the oil and oil-gas industry located in regions with a high probability of strong earthquakes, using the Fergana Oil Refinery as a case study.

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In the analytical and numerical analysis of liquid-storage tanks, the formulation of hydrodynamic pressure field of liquid has been a major research topic. [2] According to Housner [3], [4] and other early investigators, liquid motions have been assumed to be an ideal flow, and further the container flexibility as well as the liquid free-surface fluctuation has been neglected (i.e. the rigid tank model without the liquid free-surface sloshing). Later, Veletsos and Yang [5], [6], [7] expressed the importance of the container flexibility in the dynamic modeling of liquid motions. Since then, the studies on analytical and numerical formulations for the flexible tank model have been widely performed, together with the assessment on the early modeling concept, by many subsequent investigators.
As examples, Tedesco et al. [8], [9] proposed the modified analytical procedures for the free-vibration and seismic analysis of flexible cylindrical liquid-storage tanks, by refining the early work by Housner [3]. Haroun and Tayel [10], [11] presented the seismic design process for flexible tanks, by studying analytical and numerical techniques for natural frequency and added mass. On the other hand, Appa Rao et al. [12] introduced a finite element technique for computing added-mass matrix in fluid–structure interaction problems. But, in most cases, the effect of liquid free-surface sloshing, viscosity and compressibility has been ignored, according to the intrinsic judgement of its negligible contribution to the dynamic systems.
Since then, the general framework of numerical formulations reflecting the free-surface fluctuation has been established by Morand and Ohayon [2] and other researchers. On the other hand, Brebbia et al. [13] and Chopra [14] presented FEM-BEM combined numerical formulations, while Zienkiewicz and Taylor [15] FEM formulations.

Materials and methods
The primary task of this study is to evaluate the seismic strength of existing operating reservoirs based on the conclusions provided by industrial safety expert organizations. The technical characteristics of the reservoir structure are presented in Table 1.

Table 1: Technical Specifications of the Reservoir Structure

№	Description	Dimensions	Unit of Measurement
1	Height	12.4	m
2	Diameter	10.4	m
3	Wall Thickness	5.2	mm
4	Bottom Plate Thickness	2.9	mm
5	Roof Plate Thickness	2.6	mm
5	Capacity	1000	m^3
6	Design Yield Strength of Steel, R_y	245	MPa

The analysis was carried out for the following load cases:
Load Case 1 – Static load (self-weight of the structure). This load is considered as a permanent load.
Load Case 2 – Static load (static pressure of the liquid acting on the bottom and wall of the reservoir). This load is considered as a permanent load.
Load Case 3 – Dynamic load (accelerogram in the X-axis direction). This load is considered as a seismic action.
Load Case 4 – Dynamic load (accelerogram in the Y-axis direction). This load is considered as a seismic action.
Detailed information regarding the stiffness characteristics of the reservoir is presented in Table 2.

Table 2: Stiffness Characteristics of the Reservoir Structure

№	Description	Dimensions
1	Reservoir Foundation	H=50 cm
2	Bottom Plate	H=0,29 cm
3	Wall Thickness	H=0,52 cm
4	Roof Plate	H=0,26 cm

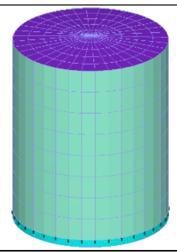

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Table 3: Mechanical Characteristics of Concrete and Steel

№	Description	Mechanical Characteristics
1	Concrete (B20)	Concrete grade: B20 Density: ρ=2,5(t/m^3); Modulus of Elasticity: E=2,7532E+05(kg/cm^2); Shear Modulus: G=1,1472E+05(kg/cm^2); Poisson's Ratio: ν=0,2;
2	Steel (C245)	Steel grade: C245 Density: ρ=7,85(t/m^3); Modulus of Elasticity: E=2,1006E+06(kg/cm^2); Shear Modulus: G=8,0558E+05(kg/cm^2); Poisson's Ratio: ν=0,3;

Results and discussion

Calculation Characteristics under Dynamic Loading

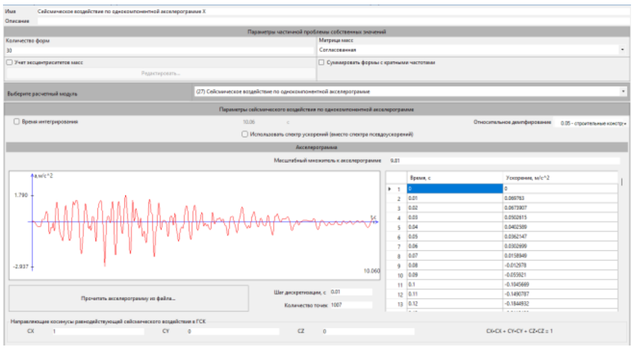


Figure 1. Dynamic Loading Along the X-Axis Direction

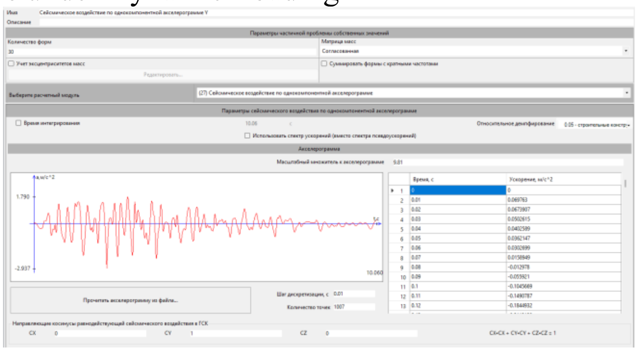


Figure 2. Dynamic Loading Along the Y-Axis Direction

Results and Discussion of the Reservoir Structure Analysis

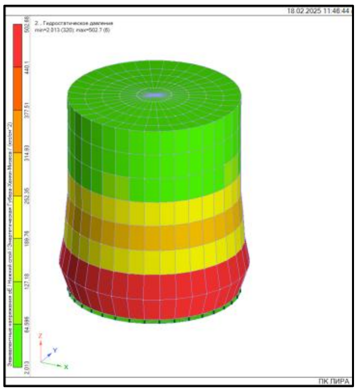


Figure 3. Equivalent Stress σE in the Lower Layer (50% Liquid Filling Condition)

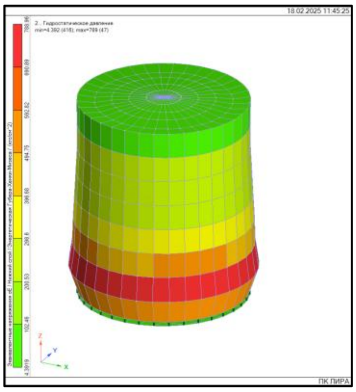


Figure 4. Equivalent Stress σE in the Lower Layer (75% Liquid Filling Condition)

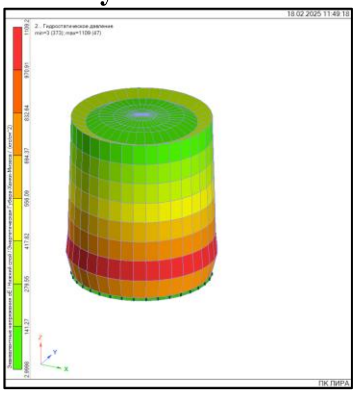
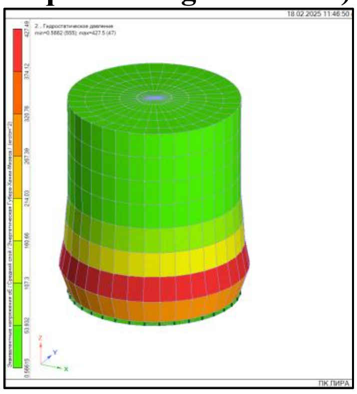
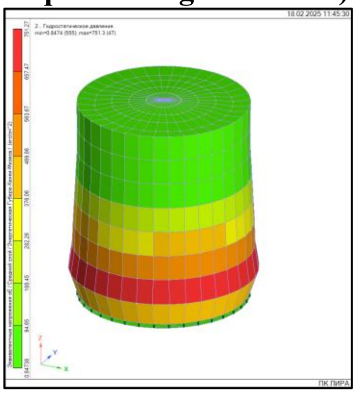


Figure 5. Equivalent Stress σE in the Lower Layer (100% Liquid Filling Condition)





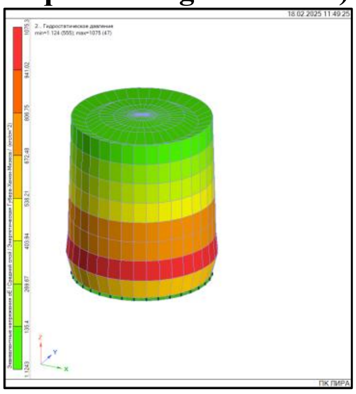


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Figure 6. Equivalent Stress σE in the Middle Layer (50% Liquid Filling Condition)

Figure 7. Equivalent Stress σE in the Middle Layer (75% Liquid Filling Condition)

Figure 8. Equivalent Stress σE in the Middle Layer (100% Liquid Filling Condition)

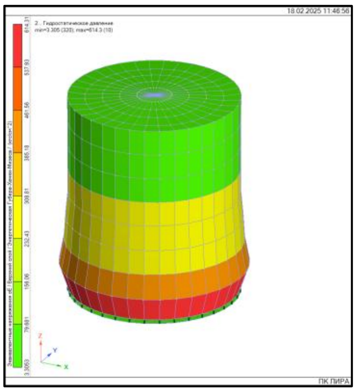

Figure 9. Equivalent Stress σE in the Upper Layer (50% Liquid Filling Condition)

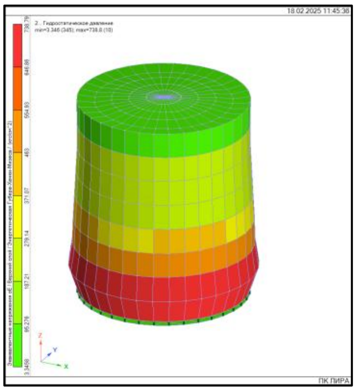

Figure 10. Equivalent Stress σE in the Upper Layer (75% Liquid Filling Condition)

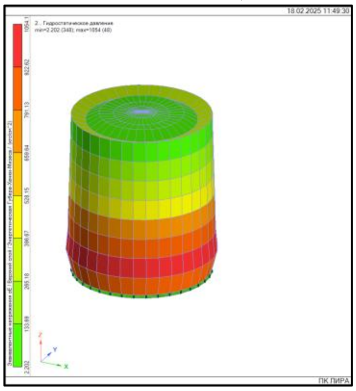

Figure 11. Equivalent Stress σE in the Upper Layer (100% Liquid Filling Condition)

The equivalent stresses σE developing in the lower, middle, and upper plates of the reservoir structure under 50%, 75%, and 100% liquid filling conditions are presented. Numerical experiments conducted using various methods for steel cylindrical reservoirs made it possible to obtain the following results. The complete calculation results of the reservoir structure are presented in Table 4.

Table 4. Discussion of the Calculation Results of the Reservoir Structure

Liquid Filling Level	%	50	75	100	Ry
Lower Layer	σE	502,68	788,96	1109,2	2450
Middle Layer	σE	427,49	751,27	1075,3	2450
Upper Layer	σE	614,31	738,79	1054,1	2450
Settlement	mm	5,9	9,05	12,4	80

Diagrammatic Representation of the Reservoir Structure Calculation Results

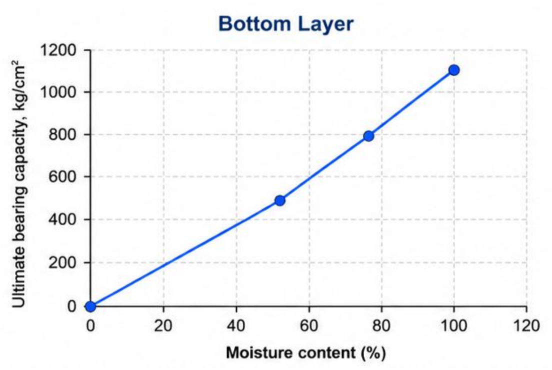

Figure 12. Diagram of the Dependence of Equivalent Stress in the Lower Layer on the Liquid Filling Level

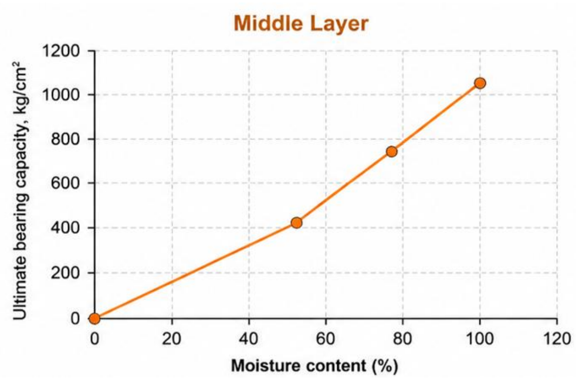

Figure 13. Diagram of the Dependence of Equivalent Stress in the Middle Layer on the Liquid Filling Level

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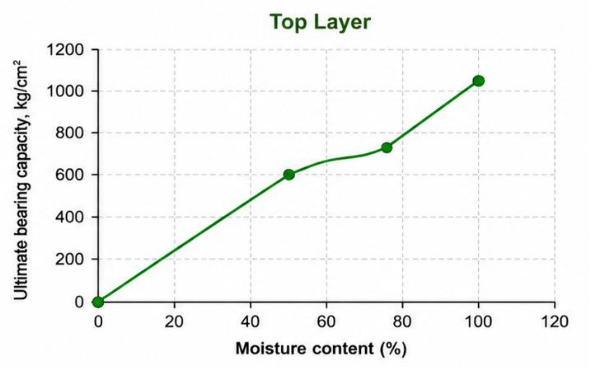

Figure 14. Diagram of the Dependence of Equivalent Stress in the Upper Layer on the Liquid Filling Level

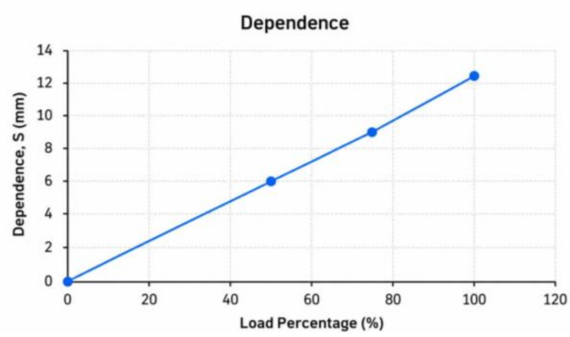

Figure 15. Diagram of the Dependence of Settlement Depth on the Liquid Filling Level

Conclusion

Based on the performed computational analyses, it can be inferred that the distribution of equivalent (von Mises) stresses in the structural plates of the steel cylindrical storage tank was evaluated for three operational filling scenarios: 50%, 75%, and 100% of the liquid capacity. The obtained results demonstrate the stress–response behaviour of the structure under increasing hydrostatic loading conditions.

For oil and petroleum product storage tanks, at a 50% filling level, the equivalent stress σE in the lower shell region is 502.68 kg/cm², in the intermediate region 427.68 kg/cm², and in the upper region 614.31 kg/cm². These results indicate a non-uniform stress distribution along the shell height and confirm an overall increase in stress response with increasing liquid volume.

At a 75% filling level, the corresponding equivalent stress values in the tank shell are 788.96 kg/cm² at the lower region, 751.27 kg/cm² at the middle region, and 738.79 kg/cm² at the upper region, reflecting a more pronounced and comparatively uniform stress development along the shell height.

For the fully filled (100%) condition, the equivalent stresses reach 1109.2 kg/cm² in the lower region, 1075.3 kg/cm² in the middle region, and 1054.1 kg/cm² in the upper region, demonstrating a significant increase in structural demand under maximum hydrostatic loading.

The foundation settlement response of the tank structure, evaluated for the same three filling conditions (50%, 75%, and 100%), yielded values of 5.9 mm, 9.05 mm, and 12.4 mm respectively, indicating a consistent increase in deformation with rising operational load.

The obtained numerical results confirm that both settlement and equivalent stress values remain within the allowable design limits. Furthermore, the structural system of the tank demonstrates sufficient stability and seismic resistance under the considered loading scenarios.

This study was conducted within the framework of the project entitled: “Assessment of the seismic resistance level of storage tanks in the oil and gas industry and development of measures to mitigate seismic risk”.

References

1. Joseph W. Tedesco, David W. Landis, Celal N. Kostem, Seismic analysis of cylindrical liquid storage tanks,
2. Computers & Structures, Volume 32, Issue 5, 1989, Pages 1165-1174, ISSN 0045-7949, https://doi.org/10.1016/0045-7949(89)90416-1.
3. H.E. Estekanchi, M. Alembagheri, Seismic analysis of steel liquid storage tanks by Endurance Time method, Thin-Walled Structures, Volume 50, Issue 1, 2012, Pages 14-23, ISSN 0263-8231, https://doi.org/10.1016/j.tws.2011.08.015.
4. J.R. Cho, J.M. Song, J.K. Lee, Finite element techniques for the free-vibration and seismic analysis of liquid-storage tanks, Finite Elements in Analysis and Design, Volume 37, Issues 6–7, 2001, Pages 467-483, ISSN 0168-874X, https://doi.org/10.1016/S0168-874X(00)00048-2.
5. G. W. Housner; Dynamic pressures on accelerated fluid containers. Bulletin of the Seismological Society of America 1957;; 47 (1): 15–35. doi: https://doi.org/10.1785/BSSA0470010015
6. George W. Housner; The dynamic behavior of water tanks. *Bulletin of the Seismological Society of America* 1963;; 53 (2): 381–387. doi: https://doi.org/10.1785/BSSA0530020381

7. S. Veletsos and J. Y. Yang, "Dynamics of Fixed Base Liquid Storage Tanks," Proceedings of US-Japan Seminar on Earthquake Engineering Research with Emphasis on Lifeline Systems, Japan Society for Promotion of Earthquake Engineering, Tokyo, 8-12 November 1976, pp. 317-341.
8. Veletsos AS,Yang JY. "Earthquake response of liquid storage tanks advences in civil engineering through mechanics". Proceedings of the second engineering mechanics specialty conference.Raleigh(NC):ASCE,1977.pp 1-24.
9. Joseph W. Tedesco, Celal N. Kostem, Arturs Kalnins, Free vibration analysis of cylindrical liquid storage tanks, Computers & Structures, Volume 26, Issue 6, 1987, Pages 957-964, ISSN 0045-7949, https://doi.org/10.1016/0045-7949(87)90113-1
10. Joseph W. Tedesco, David W. Landis, Celal N. Kostem, Seismic analysis of cylindrical liquid storage tanks, Computers & Structures, Volume 32, Issue 5, 1989, Pages 1165-1174, ISSN 0045-7949, https://doi.org/10.1016/0045-7949(89)90416-1.
11. Haroun, M.A. and Tayel, M.A. (1985), Response of tanks to vertical seismic excitations. Earthquake Engng. Struct. Dyn., 13: 583-595. https://doi.org/10.1002/eqe.4290130503
12. Medhat A. Haroun, Magdy A. Tayel Axisymmetrical vibrations of Tanks—Numerical Journal Article 1985 Journal of Engineering Mechanics 329-345 https://ascelibrary.org/doi/abs/10.1061/%28ASCE%290733-9399%281985%29111%3A3%28329%29
13. Rajasankar, J., Iyer, N.R. and Rao, T.V.S.R.A. (1993), A new 3-D finite element model to evaluate added mass for analysis of fluid-structure interaction problems. Int. J. Numer. Meth. Engng., 36: 997-1012. https://doi.org/10.1002/nme.1620360608
14. Brebbia, C. A. Vibrations of engineering structures Southampton : Computational Mechanics, 1976. vii, 387p. ill.23 cm.
15. Anil K. Chopra Dynamics of Structures: Theory and Applications to Earthquake Engineering First Edition
16. O.C. Zienkiewicz, R.L. Taylor and J.Z. Zhu The Finite Element Method: Its Basis and Fundamentals
17. Asrorovna, A. Z., Abdugofurovich, U. S., & Mirzaakbarovna, M. S. (2022). Investigation of the strength and dutness of reinforced concrete beams with glass composite reinforcements. *Spectrum Journal of Innovation, Reforms and Development*, *8*, 310-316, https://sjird.journalspark.org/index.php/sjird/article/view/450.
18. Mirzababayeva, S., Abobakirova, Z., & Umarov, S. (2023). Crack resistance of bent concrete structures with fiberglass reinforcement. In *E3S Web of Conferences* (Vol. 452, p. 06023). EDP Sciences. https://doi.org/10.1051/e3sconf/202345206023
19. Akramov, K., Davlyatov, S., & Nazirov, A. (2023). Strengthening of brickwork composite reinforcement cage. In E3S Web of Conferences (Vol. 452, p. 06005). EDP Sciences. https://doi.org/10.1051/e3sconf/202345206005
20. Akramov, K., Davlyatov, S., & Nazirov, A. (2023). Analytical calculation of bending elements with basalt fiber and glass composite rod reinforcement under short-term dynamic loading. In E3S Web of Conferences (Vol. 452, p. 06006). EDP Sciences. https://doi.org/10.1051/e3sconf/202345206006
21. Davlyatov, S., & Nazirov, A. (2023). Experimental studies of the stress-strain state of cylindrical shells. In E3S Web of Conferences (Vol. 474, p. 01019). EDP Sciences. https://doi.org/10.1051/e3sconf/202447401019