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# Analysis of the Results of Applying Prestress in Increasing Seismic Resistance of Steel Vertical Results

Timur Tursunkululy[1][a], Ulzhan Ibraimova[1][b], Akmaral Utelbayeva[2][c], Murat Sultanov[1][d]
[1]*Department of «Architecture and urban planning», Mukhtar Auezov South Kazakhstan University, Av. Tauke Khan, No. 5, Shymkent 160012, Kazakhstan*
[2]*Department of Chemistry, Mukhtar Auezov South Kazakhstan University, Av. Tauke Khan, No. 5, Shymkent 160012, Kazakhstan*
*timurtursunkululy@gmail.com*

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Abstract: At present oil and petroleum products are one of the main fuels in the world and a major source of income for many countries' budgets. It is clear that significant resources will be devoted to the restoration of the bearing capacity of existing steel cylindrical tanks. In this connection, they are considered to be particularly responsible structures, the design and construction of which should be based on strictly justified scientific provisions and technically possible, fundamentally new constructive developments, as well as optimal and cost-effective design solutions. One of such solution is prestress. Taking into account this fact, the aim of this work is a comprehensive study of seismic resistance of vertical steel tanks with the application of prestress method. It was found that the frequency of oscillations increases from 8.5% to 24.9% with an increase in the level of liquid filling, respectively with an increase in the hydrostatic pressure on the tank wall, as a result of theoretical research in the ANSYS software complex. Compared to the container without winding, the frequency of prestress container oscillation is significantly reduced regardless of the level of liquid filling in the container. Furthermore, the experimental study results of without winding tank oscillations frequency depending on the winding step and liquid filling level in the tank decreased by 6% to 18% compared with tank without winding. The results of the analysis of the experimental results show a satisfactory convergence between the values of frequencies (ranging from 1.5% to 10.1%) obtained in the design experiment and the tests of models of tank without winding and prestress winding tank. This fact indicates the reliability of the selected calculation models and obtained by theoretical value of frequency oscillations, and also justifies the proposed method of engineering calculation of frequencies and forms of oscillations of prestress winding tank.

[a] https://orcid.org/0000-0001-6215-7677
[b] https://orcid.org/0009-0004-9786-1348
[c] https://orcid.org/0000-0002-4771-9835
[d] https://orcid.org/0009-0009-1321-9400

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# 1 INTRODUCTION

At present oil and petroleum products are one of the main fuels in the world and a major source of income for many countries' budgets. It is clear that the intensive construction of steel cylindrical tanks will continue, and great attention will be paid to maintaining them in a functional and technically suitable condition and significant funds will be allocated to restore the load-bearing capacity of existing steel cylindrical tanks. The construction and operation of vertical cylindrical tanks are associated with high material costs, fire- and explosive, risk of environmental pollution, danger to human life [1-9], in connection with which they are classified as particularly responsible structures, the design and construction of which should be based on strictly justified scientific provisions and technically possible, fundamentally new design developments, as well as optimal and cost-effective design solutions.

It is also of particular importance that in the Republic of Kazakhstan, areas with high seismic activity, where oil and petroleum products storage facilities are located, being built or planned, occupy about 30% of the territory [10].

For a long time, many scientists have investigated the problem of resistance of steel tanks to operating loads. Thus, the analysis of research results of the destruction of reservoirs under seismic effects shows the complexity of their dynamic work with a simple form. The complexity of this work gives the hydrodynamic effect of the stored liquid on the tank shell, and especially the inertial component of this load [11-16]. The analysis of thin-walled steel shell structures was carried out in the work [17]. It is shown that when using shell models in addition to internal forces and membrane stresses of the shell, components of initial deformation and imperfection should be taken into account in calculations. Also taking into account the changes in shell thickness along the forming leads to a significant complication of the mathematical model [18].

Theoretical development of strength evaluation of cylindrical shells with liquid exposed to seismic effects is presented in the works [19-21], and the loss of stability of steel cylindrical shells was investigated in the works [22,23]. The possibility of reinforcing a cylindrical tank for the storage of petrochemical products with anti-cracking bands was considered in the study [24]. The results of comparative analysis of mechanical properties of structural steels and mathematical models, taking into account the influence of the temperature of the medium on the process of elastic deformation of the structures of the reservoir are presented in the works [25,26]. The issues of dent repair with carbon fiber reinforcement for the purpose of restoring the load capacity was considered in the works [27,28]. Thus, the results of studies of cylindrical composite shells, reinforced by carbon tubes are presented in the papers [29,30]. The possibility of using composite materials to increase the load capacity of tanks is shown.

The above analysis of literature data on studies of vertical cylindrical tanks dynamics in service conditions showed that, despite the simplicity of shapes and design solutions of tanks, the complexity is caused by wall thinness and liquid in the tank. It was concluded that there is currently necessity to develop design solutions for tanks for seismic areas with adjustable parameters, one of the promising directions from which is the method of prestress of tank shell by winding. It is considered that prestress winding not only reduces the stress in the tank wall, but also changes its dynamic characteristics [31-38].According to the idea of this study, the stress state control and dynamic characteristics of the tank are also considered by an effective selection of structural parameters of the prestress (pitch and angle of winding, winding force, etc.) [39-43].

# 2 METHODS AND MATERIALS

## 2.1 Theoretical study in the ANSYS software complex

The model of a typical steel vertical cylindrical tank with a volume of 3,000 m3 was investigated. The internal diameter of the tank model is assumed to be 18.38 m, and the height of the tank wall is 11.92 m. The maximum height of liquid discharge according to the design data (for seismic areas) is assumed to be 11.08 m. The Model of the wall height consists of four belts. The lower first belt has a thickness of 8 mm and height of 1.49 m, the second belt has a thickness of 6 mm and height of 1.49 m, the third belt has a thickness of 5 mm and height of 2.98 m and the upper belts have a thickness of 4 mm and height of 1.49 m. Total height of tank 2 is 11.92. The mass of the structure is 27 023 kg as shown in figure 1.

The bottom edge of the tank wall is restrained for the model in the lower T-junction.

Construction material - C245 steel with calculated resistance Rw = 240 MPa. The modulus

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of elasticity is equal to $E = 2{,}1 \cdot 10^{11}$Па, and coefficient of Poisson is equal to $\nu = 0{,}3$. The material density is ρ = 7850 kg/m3. The yield strength of steel C245 is σ 0.2 = 245 MPa. The appearance of plastic deformation zones was considered unacceptable.

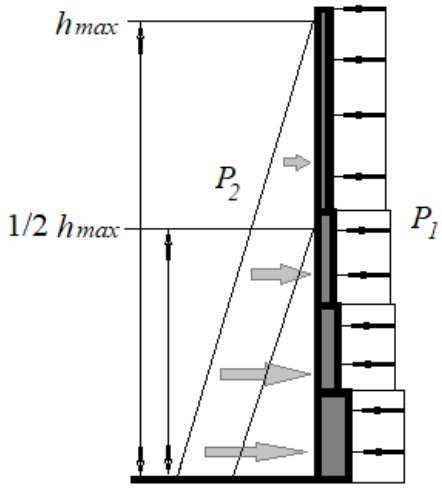
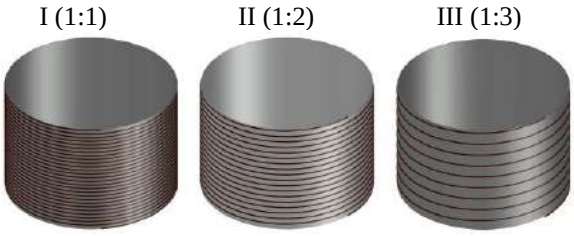



Figure 1: Structural diagram of the tank with variable wall thickness: P1 - tension of winding thread; P2 - hydrostatic pressure.

Three constructive variants of winding of prestress winding were investigated. In the first variant, the winding yarn was twisted closely to the coil with one interval in the diameter of the wire or thread, in the second variant - with double interval, and for the third - with triple interval. The options of wrapping of windings on the tank shell are shown schematically in accordance with Figure 2.




I(1:1) - single interval in wire or thread diameter; II(1:2) - Double interval in two diameters of wire or thread; III (1:3)- three interval in wire or thread diameters.

Figure 2: Winding diagram of the thread on the tank shell.

The following physico-mechanical characteristics of the winding were taken in this study. The steel wire was supposed to be made of 65T steel. The yield strength was assumed to be σ 0.2 = 785 Mpa. The diameter of the wire is $d =$ 0,004 m. The options for winding with different evenly set steps have been analyzed. At this time, the tensile strength of the wire is assumed to be equal to: 0.2; 0.4; 0.6; 0.8 from the critical winding break.

## 2.2 Experimental study of a small-scale model of steel vertical tank model

The object of study is a model of vertical steel cylindrical tank for oil and petroleum products, which was manufactured based on the similarity criteria of the model and natural tank. Geometric dimensions of model of steel vertical tank: diameter of the model D=919mm, height of the model h=596mm, wall thickness of the model t = 1mm. The winding is made of steel wire diameter d=2mm. The flat plate and bottom of the tank model are made of steel sheet. Joining the sheets together by welding with grinding welding joint.

The mechanical properties of the steel wire material and the model are given in table 1. The mechanical properties of the tension wire winding are selected according to [50,51].

Table 1: Mechanical characteristics of the wire winding material.

| Name of characteristics | Steel | $\sigma_B$, Mpa | $\delta$ % | $\psi$ % | HB, No more |
|---|---|---|---|---|---|
| Wire material Winding and tank models | Sv-08A St 08пс | 310-410 | 24 | 60 | 115 |

The general view of the vertical steel tank designs prepared for testing is presented in accordance with figure 3.

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Figure 3: General view of structural design of vertical steel tank.

In order to fully and reliably achieve the objectives of the experimental study on the basis of the main model were able to simulate: 1-traditional tank structure without winding; 2-tank with prestress winding with step of winding steel wire *a=d;* 3- The tank with prestress winding with *a = 3d* steel wire winding step.

# 3 RESULTS AND DISCUSSIONS

## 3.1 Results of theoretical study on seismic resistance of vertical steel container reinforced by winding

### 3.1.1 Analysis of the effect of winding stress force on oscillation frequencies of the prestress tank

The results of the calculations of oscillations of the tank wall of the first three forms of oscillations, taking into account the influence of winding for tank with different filling are shown in figure 4 [44-49].

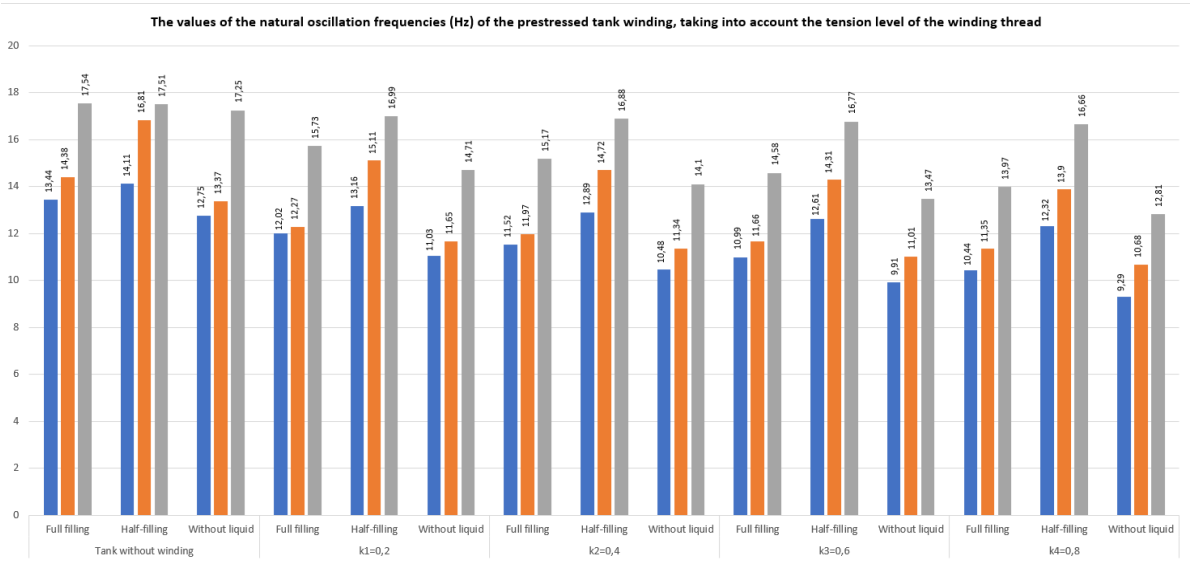


Figure 4: Values with different frequencies of the self-oscillations of the prestress tank.

As shown in Figure 4, for a fully-filled tank, the own frequency of wall oscillations is reduced with increasing the stress force of winding thread. So for comparison, if the frequency of the own oscillations of tank without winding was 13.44Hz, then for pre-winding by the pressure coil of the tank with a tension rate of thread 0.8k the frequency of oscillation was 10.44GHz.

The analysis of Figure 4 shows that when the tank is half-filled with liquid, the tension force of the winding thread does not have a significant effect on the frequency of oscillations. If the frequency of the first form of vibration of the empty without winding

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tank was 14.11Hz, then the frequency of the vibration of the tank with winding with tensioning coefficient $k_1$=0.2 -13.6 Hz, winding with tensioning coefficient $k_4$=0.8 - 12.32Hz. This fact indicates that at high hydrostatic pressures due to the increase of contact between the contact thread and the tank shell, the joint work with winding and tank shell is improved. At the same time, the rigidity of the tank shell is increased, which noticeably affects the frequency of the first forms of fluctuations of the tank wall.

The analysis of Figure 4 of a liquid-free tank shows that when the tank is empty, the tension force of the winding thread has a noticeable effect on the frequency of oscillations. If the frequency of the first form of vibration of the blank without winding of the tank was 12.75Hz, then the frequency of vibration of the container with winding with tensioning factor of thread $k_1$=0.2 -11.03Hz, winding with tensioning factor of thread $k_4$=0.8 - 9.29Hz.

The results of the study justify the possibility of regulating the dynamic characteristics of the tank with prestress winding, and therefore selecting the structural parameters of winding to improve the seismic resistance of the tank as a whole.

### 3.1.2 Analysis of the influence of the winding thread diameter on the oscillation frequencies of the prestress tank

In order to determine the influence of the thickness of winding (diameter of winding thread), studies were carried out on the displacement of tank wall with maximum liquid filling at different diameters of winding thread. The results of these studies are shown in figure 5.

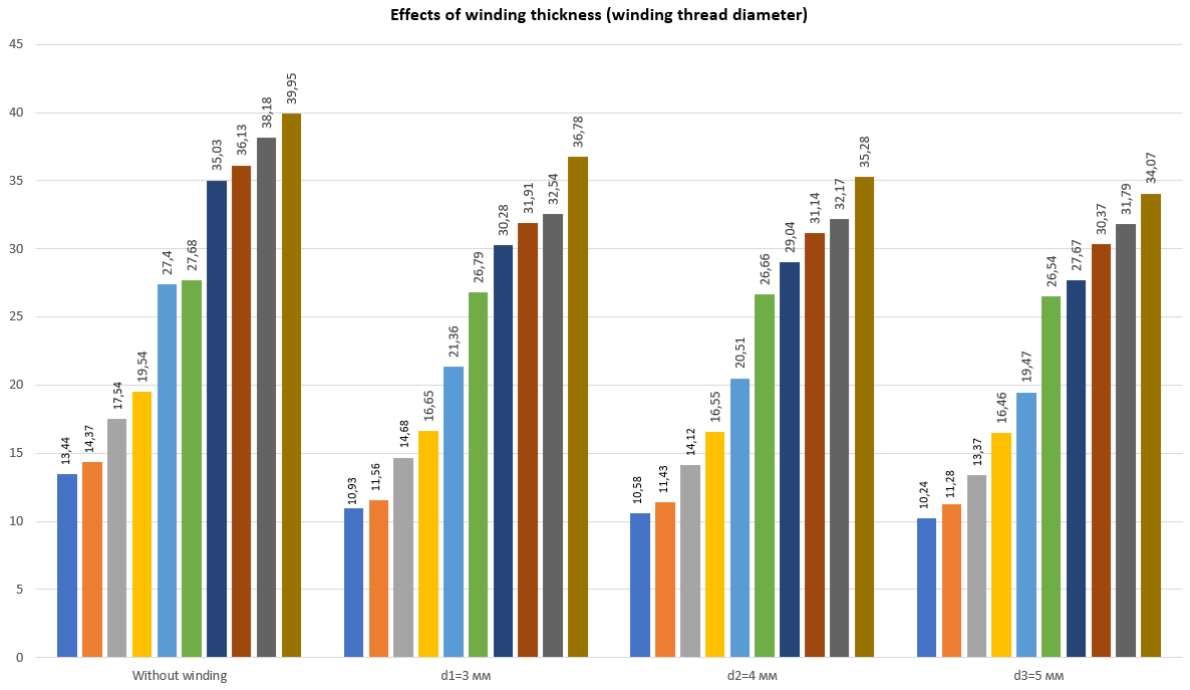


Figure 5: Frequency of oscillations (Hz) of the tank, reinforced by winding of steel wire at maximum hydrostatic pressure.

The diagram of the variation in the frequency of the tank oscillations at the maximum hydrostatic pressure with different thicknesses of winding threads confirmed a minor influence on the frequencies of the own oscillations of prestress tank of the thickness of the winding.

Based on the analysis of the change in the amount of displacements when the size of the winding diameter changes, it can be concluded that winding thread with a diameter $d_2$ = 4 mm for the construction of tank capacity of 3,000 $m^3$ is more preferable [44-49].

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### 3.1 Results of experimental study on the seismic resistance of reduced model of a vertical steel tank reinforced with winding

The tests were carried out on the cylindrical tank model of traditional designs (without winding) under different operating conditions in the first phase of the experimental studies. The case of a half-filled, full and empty tank without liquid was simulated.

The results of the treatment of the oscillograms obtained by the tests of the model of tank according to the method at 2.2, with different winding parameters and level of liquid in tank are given in figure 6 [44-49].

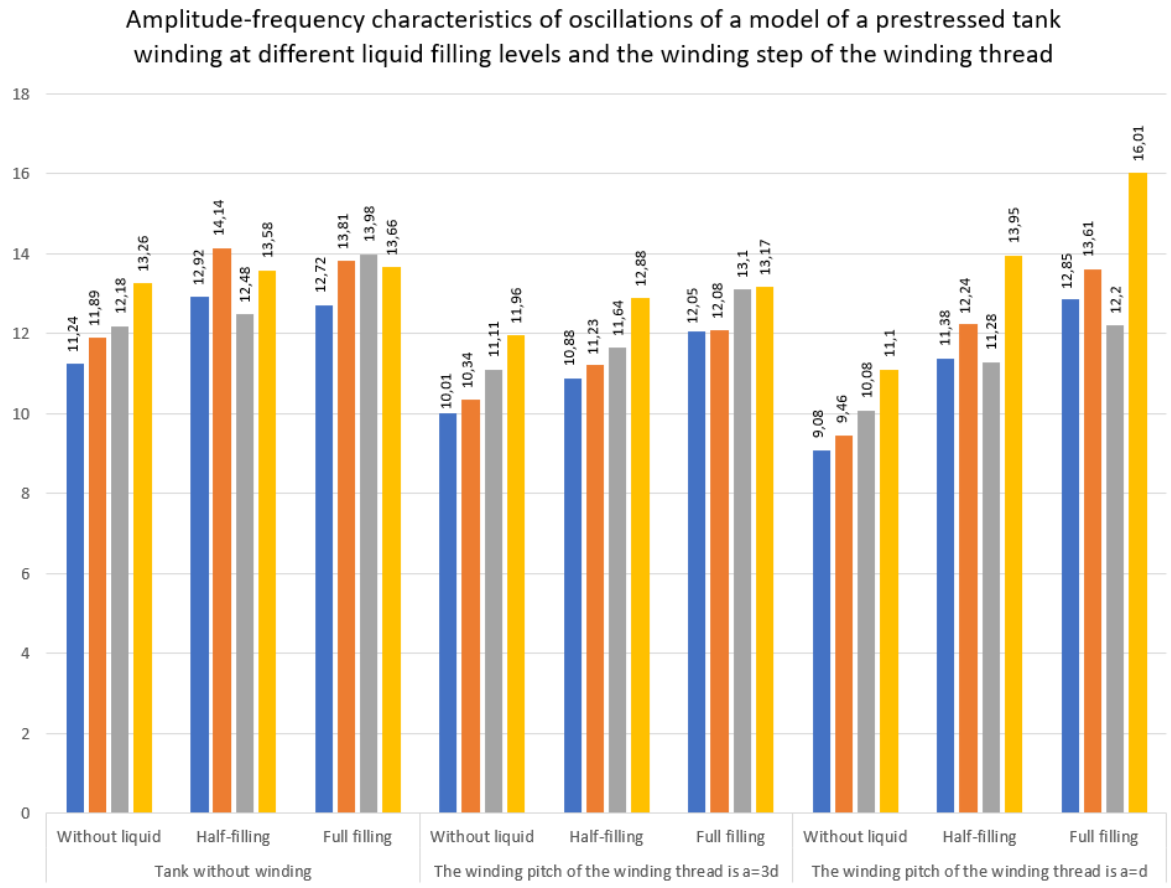


Figure 6: Eigenfrequency values of experimental studies.

The analysis of Figure 6 shows that the prestress winding has a qualitative and quantitative effect on the dynamic characteristics of tank model. As in the calculated experiment, the frequency of oscillations depending on the winding step and the level of liquid filling in the tank decreased by 6.1% to 18.2% compared with tank without winding. The amplitude of oscillations compared to the tank without winding in prestressed structures was reduced from 3.0% to 20%, which can be considered a positive point. It is of interest to change the value of the attenuation factors when strengthening the pre-stressed winding.

Thus, when comparing the design of tank without winding with a prestress tank for thread winding step *a=3d* the attenuation rate was increased by 23.0%, and when comparing the tank with winding for thread winding step a=*d*, this increase reached 32.9%. The same increase in attenuation rate is observed in liquid tanks. Thus, the value of attenuation rate with of half-filled tank a = *3d* winding thread step was increased to 8.5%, and

with winding step a = *d* reached 25%. At the maximum filling of tank, the attenuation rate was increased for a winding step a=*3d* to 14.9% and for a winding step a=*d* to 34.9%.

The results of the analysis of figures 5 and 6 show satisfactory unwinding characteristic of the values of frequencies (between 1.5% and 10.1%) obtained in the design experiment and tests of models of the tank without winding and prestress of tank winding. This fact shows the reliability of selected calculation models and obtained by theoretical value of frequency oscillations, and also justifies the proposed method of engineering calculation of frequencies and forms of oscillations of prestress tank winding. As a result of the conducted research, an invention and utility model of the Republic of Kazakhstan was patented.

## 4 CONCLUSIONS

The modeling of oscillations of vertical cylindrical tank reinforced with a prestressed winding was performed. Prestress $k \cdot \sigma_{0,2}$, 0<k<1, caused by four variants of wire tension in the winding was considered. The controlling cases for the wire tension coefficients relative to its tensile strength were investigated: $k_1=0.2$; $k_2=0.4$; $k_3=0.6$ *and* $k_4=0.8$. Variational studies were conducted taking into account additional loads caused by the action of hydrostatic pressure from a fully and half-filled tank, as well as an empty tank. Studies of the oscillation frequencies of the prestress winding of the tank were conducted without taking into account the influence of the tank roof structures:

- oscillation frequencies are decreased depending on the increase in the tension force of the winding thread from 12-27%;
- with an increase in the liquid filling level, respectively, with an increase in the hydrostatic pressure on the tank wall, the oscillation frequency is increased from 8.5% to 24.9%;
- compared to the tank without winding, the oscillation frequency of prestress tank significantly is decreased regardless of the liquid filling level in the tank;
- with an increase in the tension force of the winding thread and an increase in hydrostatic pressure, the joint operation of the winding thread and the tank body is improved, and the rigidity of the structures is increased.

Analysis of the influence of winding thickness showed that the winding thread thickness does not significantly affect the natural oscillation frequencies of the prestress tank, since the wire thickness is varied within very small limits (from 3 to 5 mm). Based on the analysis, it was concluded that winding the winding thread with a diameter of $d_2$ = 4 mm for the design of tank with a volume of 3,000 $m^3$ is more preferable.

The results of experimental studies showed that the prestress winding has a qualitative and quantitative effect on the dynamic characteristics of the tank model. The oscillation frequency of the tank without winding, depending on the winding step and the level of liquid filling in the tank, was decreased by 6% to 18% compared with tank without winding. The results of the analysis of the experimental results show satisfactory unwinding characteristic between the values of frequencies (ranging from 1.5% to 10.1%) obtained in the design experiment and the tests of models of tank without winding and prestress winding tank. This fact indicates the reliability of the selected calculation models and obtained by theoretical value of frequency oscillations, and also justifies the proposed method of engineering calculation of frequencies and forms of oscillations of prestress winding tank.

## ACKNOWLEDGMENTS

As a result of this laboratory investigation executed on the use of prestressing in shell structures, a patent [52] of the Republic of Kazakhstan for the invention was published: Method for increasing the seismic resistance of vertical steel cylindrical reservoirs by using a pre-tensioned winding, 2022, No. 35915.

As a result of this laboratory investigation executed on the use of prestressing in shell structures, a Patent [53] of the Republic of Kazakhstan for a utility model was published: Cylindrical shell for storage and transportation of liquid and hydrocarbon raw materials, 2021, No. 6208.

## REFERENCES

Koketsu, K., Miyake, H. A., 2008. Journal of Seismology, 12, 133–143.

Shigapov, R. R., Kovalchuk, O. A.,2018. SEISMIC RESISTANCE AND SAFETY OF SPECIAL STRUCTURES, 1, 14-19.

Shimizu, N., 1990. JSME international journal, 33, 111–124.

Akatsuka, H., Kobayashi, H., 2008. Japan Science and Technology Agency.
Hanson, R., 1973. National Research Council, National Academy of Sciences, - P. 331–339.
Hamdan, F.H., Constr, J., 2000. Steel Res., 53, 307–333.
Akiza Niwa, Ray, W., 1982. Earthquake engineering and structural dynamics, 10, 107-122.
Manos, G.C., Clough, R.W., 1985. Earthq. Eng. Struct. Dyn., - Vol. 13, №4, 449–466.
Haroun, M.A., Mourad, S.A., Izzeddine, W., 1991. Proceedings of lifeline earthquake engineering, 1152–1160.
SP RK 2.03-30-2017 Construction in seismic zones. State norms in the field of architecture, urban planning and construction. Rules of the Republic of Kazakhstan, Astana, 2018, https://online.zakon.kz/Document/?doc_id=36128461&pos=2;-106#pos=2;-106 (accessed on 07 March 2025)
Kangarlou, K., 2011. Bull. MGSU, 2, 131-136. https://www.researchgate.net/publication/375361908_Experimental_and_Theoretical_Reproducibility_Research_on_the_Earthquake_Resistance_of_Cylindrical_Steel_Tanks/fulltext/6547918fb86a1d521bba16ed/Experimental-and-Theoretical-Reproducibility-Research-on-the-Earthquake-Resistance-of-Cylindrical-Steel-Tanks.pdf, (accessed on 12 March 2025)
Zharova, V.D., 2018. Bull. Sci. Creat., 1, 47–51. https://www.researchgate.net/publication/375361908_Experimental_and_Theoretical_Reproducibility_Research_on_the_Earthquake_Resistance_of_Cylindrical_Steel_Tanks/fulltext/6547918fb86a1d521bba16ed/Experimental-and-Theoretical-Reproducibility-Research-on-the-Earthquake-Resistance-of-Cylindrical-Steel-Tanks.pdf, (accessed on 12 March 2025)
Kangarlou, K., 2011. Bull. MGSU, 1, 111-115. https://www.researchgate.net/publication/375361908_Experimental_and_Theoretical_Reproducibility_Research_on_the_Earthquake_Resistance_of_Cylindrical_Steel_Tanks/fulltext/6547918fb86a1d521bba16ed/Experimental-and-Theoretical-Reproducibility-Research-on-the-Earthquake-Resistance-of-Cylindrical-Steel-Tanks.pdf, (accessed on 12 March 2025)
Seismic impact on the tank with liquid https://pandia.ru/text/80/188/42942.php (accessed on 07 March 2025)
Kormanikova, E., Kotrasova, K., 2018.Composites Part B: Engineering, Volume 146, 189-197.
Spritzer, J.M., Guzey, S., 2017. Thin-Walled Structures, - Volume 119, 662-676.
Kus, J., Walach, S., 2021. International Journal of Pressure Vessels and Piping, Volume 193, 104453.
Avramov, K., Chernobryvko, M., Tonkonozhenko, A., 2018. Meccanica, Volume 53. 3339-3353.
Chemodurov, V.T., Kuzmina, S.S., 2016. Construction and safety. №2 (54), 31-34.
Duissenbekov, B, Tokmuratov, A, Zhangabay, N, Yerimbetov, B, Aldiyarov, Z., 2020. Curved and Layered Structures, 7, 48–55.
Borodin, K, Zhangabay, N.,2019. Curved and Layered Structures, 6, 236–244.
Joniak, S., Magnucki, K., Szyc, W., 2011. Strain, Volume 47, 209–214. https://doi.org/10.1111/j.1475-1305.2009.00669.x.
Al-Yacouby, A.M., Hao, L.J., Liew, M.S., Chandima-Ratnayake, R. M., Samindi, M. K., 2021. Samarakoon, Materials, Volume 14 (22), 7100.
Wang, Zh., Hu, K., Zhao, Y., 2022. J. of Constructional Steel Research, Volume 190, 107118.
Bragov, A., Konstantinov, A., Lomunov, A., Kruszka, L., 2021. EPJ Web of Conferences, Volume 250, DYMAT 2021, 04002.
Chernobryvko, M.V., Kruszka, L., Vorobiev, Yu. S., 2014. Applied Mechanics and Materials, Volume 566, 493–498.
Mariusz Maslak, Michal Pazdanowski, Janusz Siudut, Krzysztof Tarsa, 2017. Procedia Engineering, Volume 172, 723-730.
Yasniy, P.V., Mykhailyshyn, M.S., Pyndus, Y.I., Hud, M., 2020. Materials Science, 55 (1), 502–508.
Thongchom, C., Jearsiripongkul, T., Refahati, N., Roudgar Saffari, P., Roodgar Saffari, P., Sirimontree, S., Keawsawasvong, S., 2022. Buildings, 12 (2), 151.
Zhangabay, N., Ibraimova, U., Suleimenov U., 2023. Case Studies in Construction Materials, Volume 19, e02376.
Suleimenov, U., Zhangabay, N., Utelbayeva, A., Mohamad, Nr., Moldagaliyev, A., Abshenov, Kh., Buganova, S., Daurbekova, S., Ibragimova, Z., 2021. Dosmakanbetova, A., Eastern-European Journal of Enterprise Technologies, Volume 6, 7 (114), 85-92.
Zhangabay, N., Suleimenov, U., Utelbayeva, A., Buganova, S., 2023. Case studies in Construction Materials, Volume 18, e01776.
Zhangabay, N., Sapargaliyeva, B., Utelbayeva, A., Kolesnikov, A., Aldiyarov, Z., Dossybekov, S., Esimov, E., Duissenbekov, B., Fediuk, R., Vatin, N.I., Yermakhanov, M., Mussayeva, S., 2022. Materials, 15 (14), 4996.
Ibraimova, U., Zhangabay, N., 2023. Case Studies in Construction Materials, Volume 19, e02233.
Moldagaliyev, A., Zhangabay, N., Bonopera, M., Raimberdiyev, T., Yeshimbetov, S., Galymzhan, S., Anarbayev, Y., 2024. Modelling and Simulation in Engineering, Volume 2024, 1, 2827002.
Suleimenov, U., Zhangabay, N., Utelbayeva, A., Masrah, A.A.M., Dosmakanbetova, A., Abshenov, Kh., Buganova, S., Moldagaliyev, A., Imanaliyev, K., Duissenbekov, B., 2022. Eastern-European Journal of Enterprise Technologies, 7 (115), 6-20.
Suleimenov, U., Zhangabay, N., Abshenov, K., Utelbayeva, A., Imanaliyev, K., Mussayeva, S., Moldagaliyev, A., Yermakhanov, M., Raikhanova, G., 2022. Eastern-European Journal of Enterprise Technologies, 3/7 (117), 14-21.
Moldagaliyev, A., Zhangabay, N., Bonopera, M., Ristavletov, R., Ibraimova, U., Yeshimbetov, S., 2025. Vibration, 8 (1).

Zhangabay, N., Ibraimova, U., Bonopera, M., Suleimenov, U., Avramov, K., Chernobryvko, M., Yessengali, A., 2025. Structural Durability & Health Monitoring, 19 (1), 1-23.
Zhangabay, N., Ibraimova, U., Bonopera, M., Suleimenov, U., Avramov, K., Chernobryvko, M., Utelbayeva, A., Uspenskyi, B., 2024. Appl. Sci., 14 (5), 1790.
Zhangabay, N., Ibraimova, U., Ainabekov, A., Buganova, S., Moldagaliev, A., 2024. Materials, 17 (9), 1963.
Zhangabay, N., Ibraimova, U., Tursunkululy, T., Buganova, S., Moldagaliev, A., Duissenbekov, B., 2024. Materials, 17 (13), 3171.
Zhangabay, N., Bonopera, M., Utelbayeva, A., Tursunkululy, T., Rakhimov, M., 2023. Vibration, 6 (4), 960-974.
Zhangabay, N., Tursunkululy, T., Bonopera, M., Azatkulov, O., 2023. J. Compos. Sci., 7 (9), 373.
Tursunkululy, T., 2022. East-Eur. J. Enterp. Technol., 2, 14-21.
Śliwa, A., Kwaśny, W., Nabiałek, M., Dziwis, R., 2019. Acta Physica Polonica, 136 (6), 996–1000.
Tursunkululy, T., 2022. East-Eur. J. Enterp. Technol., 5, 6-13.
Tursunkululy, T., 2023. Case studies in Construction Materials, 18, e01776.
Tursunkululy, T., 2023. East-Eur. J. Enterp. Technol., 3 (7 (123), 14–25.
GOST 5663-79 Carbon steel wire for cold alighting, 1979, P-9. https://opm.ru/GOSTI_PDF/gost_5663-79.pdf (accessed on 05 March 2025).
GOST 10446 – 80 Wire tensile test method, 1980, P-9. https://rosgosts.ru/file/gost/77/040/gost_10446-80.pdf (accessed on 05 March 2025).
A patent of the Republic of Kazakhstan for the invention was published: Method for increasing the seismic resistance of vertical steel cylindrical reservoirs by using a pre-tensioned winding, 2022, No. 35915. https://qazpatent.kz/ru/search (accessed on 05 March 2025).
A Patent of the Republic of Kazakhstan for a utility model was published: Cylindrical shell for storage and transportation of liquid and hydrocarbon raw materials, 2021, No. 6208. https://qazpatent.kz/ru/search (accessed on 05 March 2025).