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EVALUATION OF CIRCULAR PRESTRESSING EFFECT ON CONDEEP PLATFORM STORAGE RESERVOIRS USING MECHANICAL PRINCIPLES

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Abstract : The prestressed concrete application of cylindrical structures is now recognized as one of the most cost-effective designs. Circular prestressing addresses the weaknesses of leakage and cracking that are common in traditional reinforced concrete tanks. It requires less maintenance, has superior fire resistance, and is a suitable substitute if steel is costly. This study investigated the entire application of circular prestressed concrete condeep platform supports and provided recommendations for a circular prestressing methodology.
Keyword :condeep platforms, circular prestressed, post-tensioned concrete, hollow concrete sections

Introduction. Condeep platforms are large concrete structures that are used for offshore drilling and storage. The main support structure is a large concrete cylinder sunk into the seabed using a technique known as gravity-based structure (GBS) (Fig 1.) GBS involves the construction of a concrete cylinder on land that is then towed to the site and sunk into place. The storage tanks on a Condeep platform were designed to withstand the weight of the stored liquids and environmental conditions. The location of the storage tanks at the top of the platform has several benefits, such as easy access for maintenance and inspection, reduction of the risk of contamination from seawater or other external sources, and prevention of damage to the tanks from marine life or other environmental factors.

Cylinders are essential components utilized in a wide range of engineering applications to confine or resist liquids entering or exiting them. A Condeep platform storage tank is used to store a variety of fluids, including water, liquid petroleum, petroleum products, and similar products. These storage tanks are built to endure high hydrostatic pressure, which is expected to be distributed equally within each layer, but fluctuates vertically along the direction of the shell.

Researchers have investigated various aspects of their design and behavior to ensure the safe and reliable performance of these structures. Among the relevant literature, Daftardar et al. (2017) presented an analytical solution for the calculation of hoop tension in liquid storage cylindrical tanks. The authors used classical bending theory to derive the formula and applied it to tanks with bottom-fixed and top-free boundary conditions. [1] It is noteworthy that Timoshenko (1959) applied the solution of the radial deformation of a tank wall to a similar or superior equation of the deflection of a beam on an elastic foundation. In certain approaches, subgrade reaction coefficients are included in the equations [2]. Lui's dissertation (1960) comprehensively analyzes the design of circular prestressed concrete tanks and proposes a seldom-used circular prestressed concrete tank approach in the United States. The study includes a dynamic analytical investigation, a detailed explanation of the proposed prestressing approach, and an illustration of the complete design procedure. Additionally, the study conducted a comparative evaluation of several commonly used circular prestressing methods to arrive at a final decision [3].

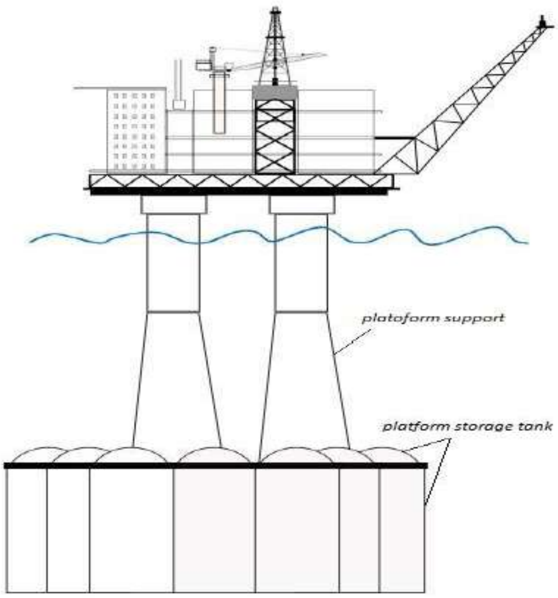

Figure 1. Condeep types offshore platform (Credit: energyfaculty) [3]

Pasternak (1932) also made a valuable contribution by presenting practical calculations for the design of folds and cylindrical shells that consider bending moments. [4] Wills (1953) investigated the design and construction of prestressed concrete reservoirs and presented a case study of a 10,000-gallon tank [5]. Finally, Nwakonobi (2015) conducted a static analysis and design of laterized concrete cylindrical shells for farm storage, which provided insights into the behavior of such structures under different loads and soil conditions. The aforementioned studies collectively demonstrate the importance of understanding the behavior and design of cylindrical tanks and shells, as well as the significance of analyzing their responses to various loads and boundary conditions [6].

This study investigates the influence of circular prestressing on the design of deep platform columns and storage tanks subjected to both internal and external hydrostatic pressures. Prestressing is a technique for increasing the strength and longevity of concrete constructions by compressing the material before subjecting it to external stress. We aimed to determine the appropriate prestressing force for Condeep platform columns and storage tanks under hydrostatic pressure, which is essential for safe and effective operation.

Analytical modelling. it is considered that the thickness of the tank wall is relatively modest in relation to its height, and the thin cylindrical shell analysis concept is applied. The tank had a closed-ring implementation. Moments and shear forces were observed mainly in the zy plane and on the horizontal edges. The material is considered elastic and isotropic, and the tangential force is constant. (Fig. 2)

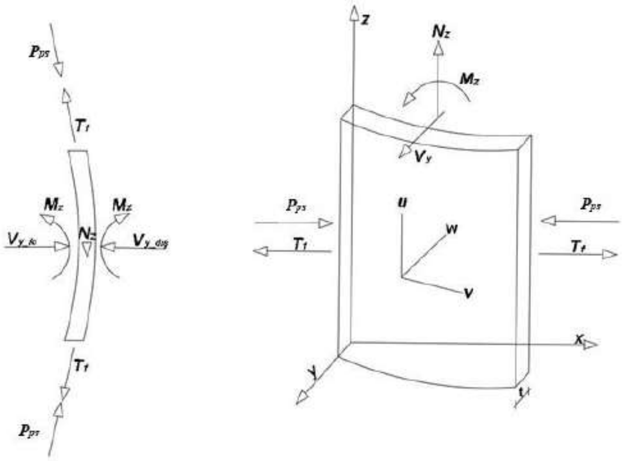

Figure 2. Internal forces and displacements scheme in Condeep platfor support sections and storage reservoir[3].

a) Force equilibrim

Force equilibrium refers to the state in which all the forces acting on a body or system are balanced, and there is no net force acting on it. For a system to be in force equilibrium, the sum of all forces acting on it must be zero.

1. The concept of equilibrium in mechanic states that if an item does not accelerate in the vertical direction (along the z-axis), the total of all the forces acting on it must equal zero.

$$\sum F_z = 0;$$

$$N_z = -\int P_z dz + C_1 \tag{1}$$

2. Similarly, the concept of equilibrium in mechanic states that if an item does not accelerate radially, the total of all the forces acting on it in the radial direction (perpendicular to the axis of rotation) must equal zero.

$$\sum F_r = 0;$$

$$\frac{d}{dz}\left(V_{y\_in} - V_{y_{ex}}\right) + \frac{T_\phi}{R} - \frac{P_{ps}}{R} + P_i - P_d = 0 \tag{2}$$

b) Compatibility equilibrium.

Compatibility equilibrium refers to the condition under which the deformation of a structure must be compatible with the applied load. In other words, the deformation caused by the applied load should be consistent with the deformation capacity of the material. This requires that the structure not undergoes any significant deformation, which would cause failure or instability.

$$\varepsilon_z = \frac{1}{E}\left(\sigma_z - \nu\sigma_\phi\right)$$

$$\varepsilon_\phi = \frac{1}{E}\left(\sigma_\phi - \nu\sigma_z\right) = -\frac{2\pi(R+w) - 2\pi R}{2\pi R} = -\frac{w}{R}$$

The vertical unit stress, also known as axial stress, is stress that is vertical, whereas the tangential unit stress, also known as circumferential stress, is stress that runs tangentially or circumferentially.

$$\sigma_z = \frac{E}{1-\nu^2}\left(\varepsilon_z + \nu\varepsilon_\phi\right) \qquad \sigma_\phi = \frac{E}{1-\nu^2}\left(\varepsilon_\phi + \nu\varepsilon_z\right)$$

$$A = 1 \times t = t$$

The vertical load or force acting on a cylindrical structure, as determined by the axial stress, σ_z, and the cross-sectional area, A

$$N_z = \sigma_z \times A = \frac{Et}{1-\nu^2}\left(\varepsilon_\phi + \nu\varepsilon_z\right)$$

$$N_z = \frac{Et}{1-\nu^2}\left(\frac{du}{dz} - \nu\frac{w}{R}\right) \tag{3}$$

$$N_z = -\int P_z dz + C_1 = 0$$

$$\frac{du}{dz} - \nu\frac{w}{R} = 0 \qquad (4)$$

Accordingly, for tangential or tension force:

$$T_\phi = \frac{Et}{1-\nu^2}(\varepsilon_\phi + \nu\varepsilon_z)$$

$$T_\phi = \frac{Et}{1-\nu^2}\left(-\frac{w}{R} + \nu\frac{du}{dz}\right) \qquad (5)$$

$$T_\phi = \frac{Et}{1-\nu^2}\left(-\frac{w}{R} + \nu^2\frac{w}{R}\right) = -\frac{Etw}{R}$$

c) Moment-curvature equilibrim

This equilibrium refers to the balance between the moments and curvatures of an element. The moment-curvature relationship is typically derived from the stress-strain relationship of the material and can be used to determine the strength and stiffness of the element.

When studying a surface's curvature, it is critical to understand the many directions in which curvature might occur. One such example is parallel to the y-plane. The curvature is represented by the variable K_z, which is defined as the reciprocal of the radius of curvature in the zy plane, indicated by R_z.

$$K_z = \frac{1}{R_z}$$

It is also critical to evaluate the behavior of a complex surface while evaluating its curvature. The xy plane is one such plane, and its curvature is defined by variable K_x. It is defined as the reciprocal of R_x and the radius of curvature in the xy plane. However, in the case of a flat surface in the xy plane, the radius of curvature becomes infinite, resulting in $K_x$equal to zero.

$$K_x = \frac{1}{R_x} = \frac{1}{\bowtie} = 0$$

By understanding how curvature affects the strain in different directions, it can better predict how a material will deform or behave under various conditions and describe the relationship between the curvature-induced strain in a material and the radius of curvature in the zy and xy planes.

$$e_z = t \times K_z = \frac{t}{R_z} \qquad e_x = t \times K_x = \frac{t}{R_x} = 0$$

The relationships among stress, strain, and curvature can help determine the behavior of materials subjected to curvature-causing external pressures.

$$\sigma_z = \frac{E}{1-\nu^2}(\varepsilon_z + \nu\varepsilon_x) = \frac{E}{1-\nu^2}\left(\frac{t}{R_z} + \frac{t}{R_x}\nu\right) = \frac{E}{1-\nu^2} \times \frac{t}{R_z}$$

$$\sigma_x = \frac{E}{1-\nu^2}(\varepsilon_x + \nu\varepsilon_z) = \frac{E}{1-\nu^2}\left(\frac{t}{R_x} + \frac{t}{R_y}\nu\right)$$

$$K_z = -\frac{d\theta}{dz} \qquad \theta = -\frac{dw}{dz} \qquad K_z = -\frac{d^2w}{dz^2}$$

$$\sigma_z = \frac{E}{1-\nu^2}\left(-\frac{d^2w}{dz^2}\right)$$

$$M_z = \sigma_z\frac{I}{C} \qquad I = \frac{1}{12}t^3$$

$$M_z = \frac{Et^3}{12(1-\nu^2)}\left(-\frac{d^2w}{dz^2}\right) = E_D\left(-\frac{d^2w}{dz^2}\right)$$

$$E_D = \frac{Et^3}{12(1-\nu^2)}$$

When we consider that it possesses flexural stiffness,

$$V_y = -E_D\left(\frac{d^3w}{dz^3}\right). \qquad ..(7)$$

We obtain the resulting equation by solving the (2) equilibrium equation.

$$-\frac{d^4w}{dz^4} - \frac{Etw}{E_D R^2} - \frac{P_{ps}}{E_D R} + \frac{P_i}{E_D} - \frac{P_d}{E_D} = 0 \qquad (8)$$

When we consider in the flexural stiffness and simplify the equation, we obtain

$$\beta = \sqrt[4]{\frac{12(1-\nu^2)}{(2R)^2t^2}}$$

$$E_D = \frac{Et}{(2R)^2\beta^4};$$

The equation's final state;

$$\frac{d^4w}{dz^4} + 4\beta^4 w = \frac{P_i}{E_D} - \frac{P_d}{E_D} - \frac{P_{ps}}{E_D R} \tag{9}$$

Coefficient verification and modification. Since equation (9) is a heterogeneous differential equation, its solution can be viewed as a combination of general (w_{gen}) and specific (w_{sp}) solutions.

$$w = w_{gen} + w_{sp} \tag{10}$$

$$\frac{d^4w}{dz^4} + 4\beta^4 w = 0$$

$$w_{gen} = e^{\beta z}(C_1\cos\beta z + C_2\sin\beta z) + e^{-\beta z}(C_3\cos\beta z + C_4\sin\beta z) = 0$$

We may recalibrate the coefficients , C_1 and C_2because H is several times bigger than t.

$$w = w_{gen} + w_{sp} = e^{-\beta z}(C_3\cos\beta z + C_4\sin\beta z) - \frac{1}{4\beta^4}\left(\frac{P_i}{E_D} - \frac{P_d}{E_D} - \frac{P_{ps}}{E_D R}\right)$$

İnternal pressure: $P_i = C'\gamma_i(H-z)R$ (11)

External pressure: $P_d = C'\gamma_d HR$ (12)

$$w = e^{-\beta z}(C_3\cos\beta z + C_4\sin\beta z) - \frac{1}{4\beta^4}\left(\frac{C'\gamma_i(H-z)R}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)$$

The coefficients C_3 and C_4 are determined from the bottom fixed supported condition.

$$w_{z=0} = 0 = C_3 - \frac{1}{4\beta^4}\left(\frac{C'\gamma_i(H-z)R}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right) = 0$$

$$C_3 = \frac{1}{4\beta^4}\left(\frac{C'\gamma_i HR}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)$$

$$\frac{dw}{dz}(z=0) = \left[\beta C_3 e^{-\beta z}(\cos\beta z + \sin\beta z) + \beta C_4 e^{-\beta z}(\cos\beta z - \sin\beta z) - \frac{1}{4\beta^4}\left(\frac{C'\gamma_i(H-z)R}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)\right]_z = 0$$

$$\frac{dw}{dz}(z=0) = \beta(C_4 - C_3) - \frac{1}{4\beta^4}\left(\frac{C'\gamma_i HR}{E_D}\right) = 0$$

$$\frac{dw}{dz}(z=0) = \beta\left(C_4 - \frac{1}{4\beta^4}\left(\frac{C'\gamma_i HR}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)\right) - \frac{1}{4\beta^4}\frac{C'\gamma_i HR}{E_D} = 0$$

$$C_4 = \frac{1}{4\beta^4}\left(\frac{C'\gamma_i HR}{E_D}\left(1 - \frac{1}{\beta}\right) - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)$$

$$w = e^{-\beta z}\left(\frac{1}{4\beta^4}\left(\frac{C'\gamma_i HR}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)\cos\beta z + \frac{1}{4\beta^4}\left(\frac{C'\gamma_i HR}{E_D}\left(1 - \frac{1}{\beta}\right) - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)\sin\beta z\right) - \frac{1}{4\beta^4}\left(\frac{C'\gamma_i(H-z)R}{E_D} - \frac{C'\gamma_d HR}{E_D} - \frac{P_{ps}}{E_D R}\right)$$

$$w = \frac{e^{-\beta z}}{4\beta^4 E_D}\left(\left(\left(C'\gamma_i HR - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\cos\beta z + \left(C'\gamma_i HR\left(1 - \frac{1}{\beta}\right) - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\sin\beta z\right) - \left(C'\gamma_i(H-z)R - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\right) \tag{13}$$

As a result, the ring tension and moment developed in the wall can be estimated using the following formula:

$$T_\phi = -\frac{Etw}{R} = -\frac{Et}{R}\left\{\frac{e^{-\beta z}}{4\beta^4 E_D}\left(\left(\left(C'\gamma_i HR - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\cos\beta z + \left(C'\gamma_i HR\left(1 - \frac{1}{\beta}\right) - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\sin\beta z\right) - \left(C'\gamma_i(H-z)R - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\right)\right\} \tag{14}$$

Eq. (15) gives an equation for the circular prestressing force and is dependent on various parameters such as the Young's modulus of the wall material, the thickness of the wall, the radius of curvature, the depth of the wall, and other parameters such as the coefficients of pressures and the prestressing force. This equation involves several terms with trigonometric and exponential functions and can be used to estimate the circular prestressing force at different wall depths.

$$M_z = -E_D\left(\frac{d^2w}{dz^2}\right) = \frac{e^{-\beta z}}{2\beta^2 E_D}\left(\left(C'HR(\gamma_i - \gamma_d) - \frac{P_{ps}}{R}\right)\sin\beta z + \left(C'\gamma_i HR\left(1 - \frac{1}{\beta}\right) - C'\gamma_d HR - \frac{P_{ps}}{R}\right)\cos\beta z\right) \tag{15}$$

Eq. (16) gives an equation for the moment, and is also dependent on parameters similar to Eq. (15). The formula involves second-order differentiation of the wall deflection with respect to the depth and includes terms with trigonometric and exponential functions. This formula can be used to estimate the moment at various wall depths. As a case study, the basic mechanical formulas (15) and (16) allow us to accurately evaluate the changes in tension (Fig. 3) and moments (Fig. 4) obtained by circular prestressing in a shell at a depth of 100 m. This data may be applied to best prepare the condeep structure's design and ensure that it can handle the projected loads and environmental conditions.

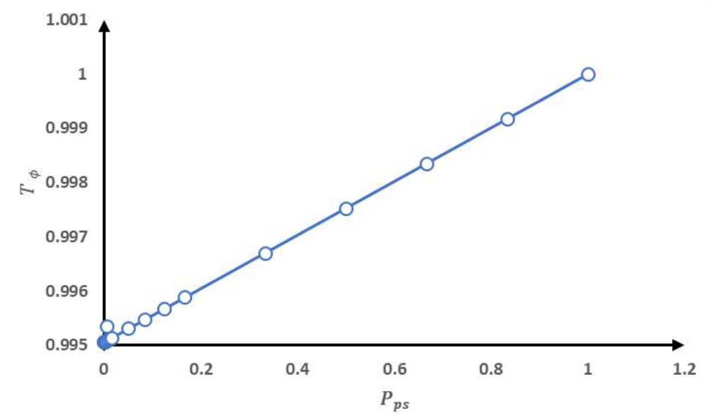

Figure 3. Tension force changing from the effect of prestressing force [6]

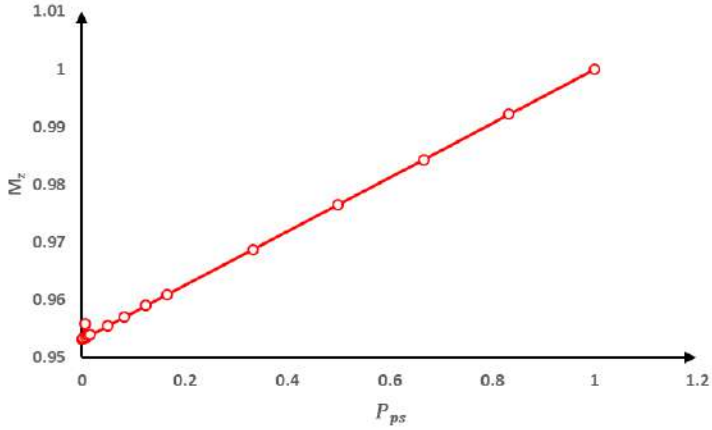

Figure 4. Moment changing from the effect of prestressing force [6]

The proper distribution of ring tension and prestressed force is essential for system analysis and performance. (Fig. 5). It affects the level of stress and strain experienced by the system, and the mode of failure of the system. If the forces are evenly distributed, the system may fail in a controlled manner, allowing for proper mitigation measures to be taken. Therefore, it is important to prioritize the even distribution of these forces and ensure that they are properly balanced.

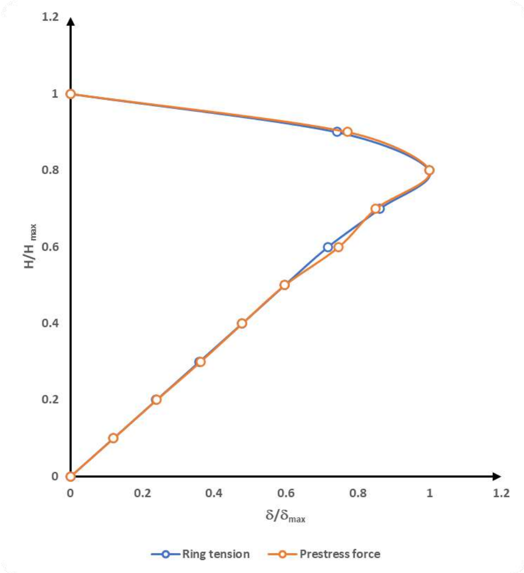

Figure 5. The distribution of ring tension and prestress force along the length of structure for the dicplaced structure [6]

Discussion and conclusion. For a constant-thickness case, the provided equations can be implemented with a low error rate. In a cylindrical tank, circular prestressing is used to generate pressure that opposes and balances the hydrostatic water pressure. Because the specified segment was submerged in water, the impact of the external liquid was sufficient to counterbalance the hydrostatic pressure within the structure of Condeep's multiple marine platforms. However, circular prestressing does not provide a significant advantage for Condeep-type platforms, as demonstrated by Fig. (3) and (4). Instead, it adds stress to the reinforced concrete section by either "supporting" the external pressure or increasing the magnitude of the stresses. The impact of the circular prestressing force can balance the moment produced by the external load when the prestressed concrete tank is full. This is the primary benefit of prestressing during concrete tank construction. When the tank is empty, only the bending effect of the circular prestressing wire occurs. In most cases, an empty tank represents the critical design condition. Hence, it is essential to investigate the tensile stresses induced by prestressing forces. For instance, it may be advantageous to add conventional mild steel-reinforced bars to handle tensile loads, resulting in partial prestressing.

Definitions and abbreviations

P_z – Vertical pressure

T_ϕ –Tangential force or ring tension

P_i –İnternal forces

P_d –External force

R –Radius of Condeep supports

P_{ps} –Prestressed force

E_D –flexural stiffness

C' – Impact factor

γ_i – Density of liquid inside

γ_d – Density of liquid outside

H –height of structure

V – Shear force

M –Bending moment

w – Radial displacement of sturcture

References

1. Anand Daftardar, Shirish Vichare, Jigisha Vashi. (2017): An Analytical Solution for Hoop Tension in Liquid Storage Cylindrical Tanks, International Journal of Engineering and Applied Sciences (IJEAS), pp. 99-104.
2. Timoshenko S.P., and Woinowsky-Krieger S. (1959), Theory of Plates and Shells, 2nd Edition, McGRAW-HILL, New York.
3. Liu, Chi-Yek. "A study of the complete design for circular prestressed concrete tank and its dynamic analysis." PhD diss., Virginia Tech, 1960.
4. Pasternak P. L. (1932), Practical Calculations for Folds and Cylindrical Shells Taking Bending Moments into Account, Stroitelny byulleten,
5. Wills, R. F. (1953). Prestressed concrete reservoirs. New Zealand Engineering, 8(2), 54-59.
6. Nwakonobi, T. U. (2015). Static Analysis and Design of Laterized Concrete Cylindrical Shells for Farm Storages (Doctoral dissertation).
7. Creasy, L. R. (1958). Prestressed Concrete Cylındrıcal Tanks. Proceedings of the Institution of Civil Engineers, 9(1), 87-114
8. Eremeev, V. V., & Zubov, L. M. (2017). Buckling of a two-layered circular plate with a prestressed layer. Mathematics and mechanics of solids, 22(4), 773-781.
9. Liu, C. F., & Chen, T. J. (2013). A simple and unified displacement field for three-dimensional vibration analysis of prestressed circular plates. Journal of Vibration and Control, 19(1), 120-129.

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