PARAMETERS DETERMINING THE DEGREE OF THE REQUIRED EXTERNAL TRANSVERSAL FRP REINFORCEMENT OF METAL CYLINDRICAL TANKS

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The main reasons for the wear of the walls of metal cylindrical tanks are corrosion and fatigue of the metal of their vertical joints. It is possible to replenish for the corrosion losses of the material, as well as to reduce the level of acting stresses to values allowed by the conditions of metal fatigue, with external transverse reinforcement with fiber reinforced plastic (FRP).

The purpose of the work is to determine an applied method acceptable for the calculation of metal cylindrical tanks that perceive internal pressure and are reinforced by external transversely directed FRP reinforcement, taking into account differences in the temperature deformation of the used materials, as well as the definition of general factors affecting the efficiency of the applied solution.

Results of the research. Sequential consideration of the operation of the steel shell of a cylindrical tank, having a radius r and thickness t_s , being under the action of the initial internal pressure P' and than strengthened by transverse prestressed FRP elements with prestress σ_{f0} and thickness t_f continuously located along its height, experiencing a subsequent increase in pressure by an amount ΔP, made it possible to obtain the values of the maximum hoop stresses, respectively, in the elements of FRP reinforcement and the steel wall of the tank:

$$\sigma_f = \sigma_{f0} + \frac{m\left[N_{f(x,z)} + t_s E_s\left(\alpha_s \Delta T_{s2} - \alpha_f \Delta T_{f2}\right)\right]}{t_s + t_f m},$$

$$\sigma_s = \frac{P' \cdot r}{t_s} - \sigma_{f0}\frac{t_f}{t_s} + \frac{N_{s(x,z)} + t_f E_f\left(\alpha_f \Delta T_{f1} - \alpha_s \Delta T_{s1}\right)}{t_s + t_f m},$$

where $N_{f(x,z)} = \Delta P \cdot r\left(1 - \mu/2\right)$, $N_{s(x,z)} = \Delta P \cdot r\left[1 + m\left(t_f / t_s\right)\left(\mu/2\right)\right]$ – conditional ring forces per unit section of the FRP and steel layers of the tank wall, arising from a change in internal pressure by the value ΔP and determined taking into account the combined action of ring and longitudinal stresses in the steel part of the structure; E_s , E_f –

respectively, the modules of elasticity of steel and elements of FRP; $m = E_f / E_s$ – the ratio of the elastic modules of the constituent layers of the wall; μ – Poisson's ratio of the material of the steel component of the tank wall; σ_{f0} – prestressing in the elements of FRP; α_s and α_f – coefficients of linear thermal deformation of steel and a layer of FRP; ΔT_{s1} and ΔT_{f1} – the most critical temperature changes of the steel and FRP components of the shell, causing maximum additional stresses in the steel; ΔT_{s2} and ΔT_{f2} – the most critical changes in the temperatures of the steel and FRP components of the shell, causing the maximum additional stresses in the FRP.

The most typical case that determines the temperature regimes is a smooth change in temperatures with the same values ΔT in all layers of complex walls. At present, two fundamental approaches have been formed to the practical consideration of the nature of the operation of such cylindrical shells.

On the one hand, classical works, which analyze the strengthening of metal cylindrical shells by winding high-strength metal wires and tapes, state that taking into account the longitudinal stresses of these structures leads to a slight increase in the thickness of the steel parts of the walls and a decrease in the thickness of the reinforcing layers.

On the other hand, the distinguishing features of the use of external FRP reinforcement of tanks from reinforcing winding by metal elements are a much larger possible range of ratios of the elastic modules, as well as the coefficients of linear thermal deformation of FRP cause a significant increase in stresses during combined work with steel.

The case of abstraction from longitudinal deformations of metal shells of tanks. Combined consideration of expressions defining stresses in the steel wall of the tank and reinforcing FRP elements, abstracted from the longitudinal stresses of the shell (i.e. $N_{f(x,z)} \approx N_{s(x,z)} \approx (\Delta P) r$), allows to get the coefficient of the required degree of external FRP reinforcement

$$k_{f(t)} = \frac{t_f}{t_s} = \frac{\Delta\sigma_{s+}}{\left(f_{yd} + \Delta\sigma_T\right) m},$$

where $\Delta\sigma_{s+} = \frac{\Delta P \cdot r}{t_s} - f_{yd}$ – conditional excess of stresses over its limiting value f_{yd} (yield strength of steel or maximum stresses determined by the fatigue of the material of the joints) in a metal shell in the absence of external reinforcement; $\Delta\sigma_T = \left(\alpha_s - \alpha_f\right) \cdot \Delta T \cdot E_s -$ the value that determines the change in stresses under the influence of temperature deformations.

The case of accounting for longitudinal deformations of the metal shells of tanks. Similar to the previous case, the combined consideration of the expressions that determine the stresses in the steel wall of the tank and the reinforcing FRP elements, taking into account the effect of longitudinal stresses in the shell on conditional ring forces $N_{f(x,z)}$, $N_{s(x,z)}$,), allows to get the coefficient of the required degree of external FRP reinforcement

$$k_{f(t)} = \frac{t_f}{t_s} = A_3' - A_2 / A_1 ,$$

where $A_1 = m\left[\left(1 - \mu/2\right) f_{yd} - \left(\mu/2\right)\Delta\sigma_{s+} + \Delta\sigma_T\right]$,

$$A_2 = \left(1 - \mu/2\right) f_{yd} - \left(1 + \mu/2\right)\Delta\sigma_{s+} + \Delta\sigma_T , \; A_3' = 1/m .$$

Numerical studies and related analysis, taking into account the effect of longitudinal deformations of tanks, allows to conclude that it is quite expedient to use low-modulus and much cheaper FRP to reinforce structures that have high strength characteristics of steel basics $f_{yd} \approx 30...42 kN/cm^2$. At the same time, as for structures characterized by low strength limits of steel $f_{yd} \approx 15...20 kN/cm^2$, effective external reinforcement is achieved only when using high-modulus FRP.

Conclusion. The proposed calculation methods make it possible to determine the necessary parameters for strengthening the bodies of metal cylindrical tanks with an external transversely directed FRP reinforcement that perceives the actions of ring forces. The main factors determining the effectiveness of the solutions obtained are the residual strength of the material of the metal shells of the tanks, as well as the modulus of elasticity of the used FRP. The theoretical expediency of the effective use of low-modulus FRP is confirmed for structures with high strength indicators of metal bases, and high-modulus – for the walls of tanks, which are characterized by significant restrictions on the level of allowable stresses of their metallic shells.