Development of shell structures in geotechnics and increasing their reliability and safety in modern conditions

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Abstract. In the interests of sustainable development of the country, improving the quality of the living environment of the population, ensuring environmental safety, it is necessary to create scientific and technological potential, which is noted in the Decree of the President of the Russian Federation and the Resolution of the Government. Based on the foregoing, this article discusses the issues of improving shell structures, composite nanomaterials, their reliability, longevity and stability in natural climatic, technogenic, social and environmental factors. A feature of the above shell structures is their ability to maintain their design shape after various influences, which is laid down in the design and technological processes. The use of shell structures made of various composite (fabric, metal-cord and rubber-fabric, etc.) materials was most widespread in the 70s and 80s of the previous century, which is characterized by the creation of various scientific schools: Sergeev B I - soft hydraulic structures; Petrakov B I - pneumatic dams, pneumatic formwork; Blinov Yu I - awning structures; Ermolov - pneumatic building structures; Stepanovich G Ya, - retaining structures for mine workings, etc. Significant successes in the creation of composite materials were made by foreign firms (Japan, Italy, USA, England, etc.).

However, the shortcomings of the technical manufacturing conditions, well-grounded computational studies hindered the widespread introduction of such structures. The development of the rubber industry in the 80s made it possible to create protective complexes of structures from shell structures for the climatic, social and other conditions of the life of the population of our country [1-4].

To ensure safety and reliability, operability of shell structures for hydraulic and reclamation construction at the Kursk rubber plant (KRTZ) in 1987 under the leadership of V I Kasharin, candidate of technical sciences and Deputy Director for Science of the KRTZ plant V I Monayev technical conditions were developed for the manufacture of rubber-cord panels for hydropower dams, which were subsequently manufactured in workshop number 5 with the participation of the head of the workshop Kryazhev Yu I this device (figure 1). The sheets of rubber-cord material and the shutter were operated for 5 years without dismantling and changing the design position, incl. in winter. During the survey, it was revealed that in the upper part of the panel, in the adjacent to the coastal part, scuffs were noticed [2].

Subsequently, similar products were used in the creation of retaining structures on the Bolshoi Stavropol Canal (BSK-3) (figure 2), as well as in the Rostov region during the construction of retaining aeration structures under the guidance of graduate student D V Kasharin on the river Malaya.
Chuburka on a soil-reinforced float bet, as well as on the Bagaevsko-Satkovskaya discharge system and during the construction of a hydropower facility at the Olginsky test site [5].

![Figure 1](image1.png) (a) is diagram of the dam; (b) is dam on the Rogoznya river, Kursk region.

![Figure 2](image2.png) Hydraulic dam at BSK-3.

However, these composite materials were heavy and were very inconvenient in the manufacture and assembly of structural elements. Currently we use composite materials like UNISOL.

Hydraulic shell structures are affected by various types of loads: water, soil, etc. The influence of the water flow subjects the structures to dynamic loads, i.e. at $H_d \sim 0.7H_d$, a soft and then hard loss of stability in the form of a dovetail begins, which leads to the destruction of shell systems [4].

We propose the use of multifunctional multilayer shells, where one of the layers is materials of plant and artificial origin with the addition of composite rubber-cord elements, ensuring the stability of structures under dynamic influences, i.e. will work like an elastic bar [5].

This will allow them to be used in the creation of protective structures under various natural and climatic influences on building structures, i.e. with abrupt changes in the cross-sectional parameters of an elastic and tenacious rod at different values of the compressive force. Such shell-rods must have elasticity and have a flexible structure inside with tribological properties, which are acquired at the manufacturing stage and can be combined into a single object while maintaining general properties that can interact in various media (water, air, solid and liquid pollution, etc.) i.e. composite fibrous material with desired properties, impregnated with a viscous lubricant. One of these shells is shown in figure 3 [3, 4].

In this case, the implementation of the hydraulic or elastodynamic regime of the lubricant itself should be taken into account, which practically excludes wear of the contacting surfaces, and friction is minimal. In this case, the coefficient of thickness of the lubricating film should be taken into account.
To obtain the value of $\lambda$, the following characteristics must be taken into account: friction process (V-speed, P-load, T-temperature); contacting bodies (surface roughness, ultimate modulus of elasticity, Poisson's ratio, and reduced radius of curvature of surfaces); lubricant (viscosity, piezoelectric coefficient of viscosity, temperature coefficient of viscosity). Here it should be taken into account that liquid lubrication is recommended at $\lambda > S$, and at the mode of adjacent friction $1 < \lambda < 3$, i.e. with the participation of hydrodynamic lubrication, which is adopted during their technological manufacture. All of the above should be carried out for the absence of jamming (at a critical temperature, i.e., the fulfillment of the condition of survivability and durability of composite nanomaterials) (figure 4 [6-8]).

The use of such technological conditions in the creation of composite nanomaterials with predetermined properties will make it possible to implement the technical solutions given below (figure 5 [9-13]).

**Figure 3.** Multilayer shell element made of heterogeneous composite nanomaterials: 1 is filler; 2 is soil foundation; 3 is shells made of durable composite nanomaterial; 4 is interlayer of fibrous synthetic or plant materials with tribological properties.

**Figure 4.** Arrangement of buildings on frozen ground: 1 is building; 2 is walling; 3 is multilayer base shells; 4 is piles; 5 is active layer; 6 is frozen ground (permafrost); 7 is solar panels.
We propose a dependence to justify the reliability and environmental safety of shell structures in the form of dynamically developing simulation models according to the proposed dependence:

$$P_r, E_s = f (F_1, F_2, F_3; T; D; \beta_1, \beta_2; m; K; C)$$

where $P_r$ is the reliability of the operation of multifunctional, multilayer heterogeneous shell structures during the service life $t$, taking into account their technological manufacture, tribology, multilayerness; $E_s$ is ecological safety of structures, including observations of: durability; their durability in specific natural and climatic conditions and their use as a recyclable material to preserve the environment; $F_1, F_2, F_3$ is natural and climatic, technological, social impacts; $T$ is design life of the elements of shell structures with technological potential, taking into account the multi-layer, incl. fibrous materials and their tribology; $D$ is deformation of shell structural elements during operation; $\beta_1, \beta_2$ is external and internal dynamic influences; $m$ is composite nanomaterials; $K$ is change in the base soils in various natural and climatic conditions; $C$ is impact on the environment during the period of operation.

Below are experimental studies of modern composite materials (elastomers) were carried out in the MISiS laboratory on a universal tensile testing machine INSTRON 150LX (figure 6, table 1).

![Figure 6. Testing of composite materials on a universal tensile testing machine INSTRON 150LX (NRU MISIS): a - general view of INSTRON 150LX; b - non-contact video extensometer; c - mounted sensors; d - testing at NRU MISIS.](image)

| Names of characteristics | Maximum values |
|--------------------------|----------------|
| Maximum frame load, kN   | 150            |
| Working stroke, mm       | 305            |
| Test speed, mm/min       | 228            |
Determination of the stress-strain rate between the aggregate and the shell of the soil-filled structure is shown in figure 7.

**Figure 7.** Graphs of linear tension versus filling height $N$ (h): (a) is filling soil sand; (b) is sandy loam filling soil; (c) is clay loam

Below is the use of FEM for calculating soil-filled shells, which are used as retaining structures and foundations.

SolidWorks Simulation uses the following conventions. Directions $X, Y,$ and $Z$ are referred to the global coordinate system.

Equivalent Strain (ESTRN) is defined as:

$$ ESTRN = 2 \left[ \left( \frac{\varepsilon_1 + \varepsilon_2}{3} \right)^2 \right] $$

where

$$ \varepsilon_1 = 0.5 \left[ \left( EPSX - \varepsilon^* \right)^2 + \left( EPSY - \varepsilon^* \right)^2 + \left( EPSZ - \varepsilon^* \right)^2 \right] $$

$$ \varepsilon_2 = 0.5 \left[ \left( GMXY \right)^2 + \left( GMXZ \right)^2 + \left( GMYZ \right)^2 \right] / 4 $$
Three components of normal stresses are taken into account.

To assess the reliability of the shell, the von Mises equivalent tension is determined based on six stress components:

$$VON = \left(0.5 \cdot \left[ (SX - SY)^2 + (SX - SZ)^2 + (SY - SZ)^2 \right] + 3 \cdot (TXY^2 + TXZ^2 + TYX^2) \right)^{1/2}.$$  

For non-closed soil-filled shells, the Simulation software (Solid Works application) was also used for numerical modeling.

Below is the structure of simulation modeling of engineering protection structures using new technical solutions (figure 8).

Simulation models of engineering protection structures for the infrastructure of small recreational facilities created in the Matlab 2016 software environment in the Simulink module are shown in figure 9.
According to the given operating conditions for shell structures made of composite materials, the authors have developed and are developing new technical solutions, simulation models and scientifically grounded recommendations for their application in the national economy under various influences, including natural and man-made (flooding, flooding, landslide and erosion processes, frozen soils, dynamic effects, etc.) [14,15].

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