Restoration of underground water-carrying structures damaged by external non-stationary impacts

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Abstract. Object and purpose of the study: Underground aquiferous point and linear structures operated in difficult ground conditions lose their structural safety as a result of the influence of external forces and the *environment.* It is important to establish the features of the operation of underground aquifers and communications in an inhomogeneous enclosing soil massif, taking into account the interaction of structures with the ground in case of non-stationary force impacts and environmental impacts with an assessment of their structural safety. Methods: The use of analytical and experimental research methods to evaluate the work of structures in the soil mass, taking into account force influences and environmental influences. Results: The features of interaction of the housing of a collapsible pipe with a soil mass with a multidirectional horizontal component of a non-stationary load are established. The negative impact of the combination of the multidirectional impact of the power load and internal hydrostatic pressure on the structural safety of the housing of a prefabricated underground structure is shown. Practical significance and conclusions: The results obtained on the picture of the stress-strain state of an inhomogeneous enclosing soil massif allowed us to establish the nature and boundaries of the safe operation of structures and to make suggestions on the choice of ways to strengthen and protect underground structures, taking into account their operating conditions. Keywords: Underground Structures, Heterogeneous Soils, Non-stationary Impacts, Structural Safety, Protection Methods.

1 Large-sized underground pumping stations

1.1. Interaction of a massive underground structure with an inhomogeneous soil environment

The process of immersion of massive shells of large diameter D = 50m and above into inhomogeneous soils at depths of H = 60-70m is accompanied by the effect of unsteadiness. There is an uncontrollable impulse of instantaneous disruptions of the descending structure

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[1,2]. The stress-strain state (SSS) of the lowering structure necessitates computer modeling and calculations of all stages of the "construction-immersion-operation" life cycle [3].

The experimental results performed by the author on real objects of construction of lowering structures confirm this research hypothesis (see Fig. 1) Computer modeling of the interaction processes of the system "lowering structure - ground mass" at the stage of immersion and operation showed the moments of occurrence of dangerous situations and the causes of structural safety violations in the elements of the structure, which received the maximum stress-deflated state (SSS) during structural failures [4].

The results of modeling and monitoring make it possible to create an adapted regime for the construction of a large-sized descending structure in difficult soil conditions. Characteristics of the stages of modeling during the construction of a large-diameter underground structure to a depth of more than 50 m. Hodograms of the processes of erecting a reinforced concrete shell and excavating soil from the internal cavity, monitoring and the results of geodetic measurements and monitoring the construction stages of projectile deviation from the vertical axis are presented [5,6]. At the stage of immersion of dangerous structural failures, geotechnical methods are used to control the interaction of the elements of the “lowering structure - soil massif” system (see Fig. 2). The targeted application of geotechnical methods provides control over the process of twisting a massive shell into heterogeneous soils and creates conditions for its structural integrity. The results of modeling and monitoring make it possible to create an adapted mode for the construction of a large-sized lowering structure in difficult ground conditions. The point application of geotechnical methods provides control of the process of spinning a massive shell into inhomogeneous soils and creates conditions for its structural safety.

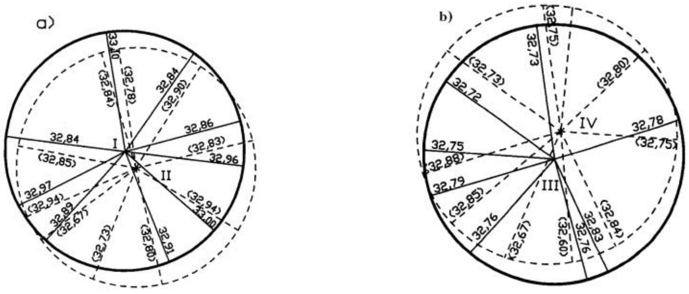
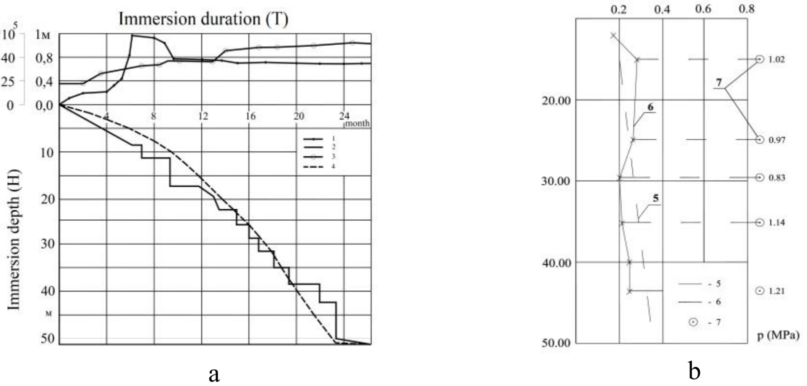


Fig. 1. Shell deformations: a - when immersed in inhomogeneous soils up to 20.0m; b- when the shell is immersed in inhomogeneous soils to a depth of more than 30.0m.

The scientific concept of the author differs from the previously accepted method of calculation for sinking and allows us to study the conditions of interaction of elements of an underground structure with the ground environment at all stages of the life cycle.



a b

Fig. 2. The monitoring results for the immersion of a large sunk well: a) motiongramm of immersion; b) monitoring data. 1 – diagram of vertical misalignment (careen); 2 – diagram of immersion; 3 – weigh of the well shell; 4 –ditch bottom; 5,6,7 – correspondingly, calculated, averaged and peak values of lateral soil pressure.

When a massive reinforced concrete shell is immersed in heterogeneous soils, there are situations of combining the modes of erecting a structure and excavating soil from the shell cavity. To analyze the development of these processes and the possibility of their r. egulation, it is impossible to apply analytical methods of calculation [7,8].

1.2. Protection of an underground pumping station from sudden immersion

With the help of computer simulation, the immersion process is calculated and the situation of sudden shell failures is simulated. For modeling and calculations, the finite method (FEM) and programs for design and geotechnical calculations [9,10].

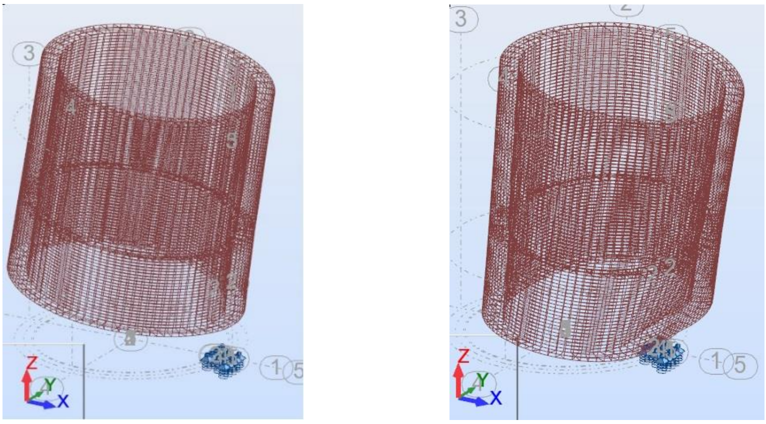


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Fig. 3. Fragments of calculations (from a series of 384 calculation schemes) of a reinforced concrete shell with a mass G= 1,2x10MN) at the stage of unregulated immersion with shape change characteristics.

Fragments of the calculation of non-stationary immersion of a large-sized massive reinforced concrete shell (with a diameter and depth of more than 70 m, with a wall thickness of 2.5 m and the number of volumetric finite elements up to 364 thousand elements), falling under its own weight at an angle of 12 ° - 24 ° from an estimated height of up to 280 cm height onto pliable soil of different strength soil (from E= 4 MPa to E= 19 MPa). For geotechnical analysis and modeling (Fig. 5.), a geological section and engineering-geological layers characteristic of the conditions of immersion of large-sized reinforced concrete shells were adopted: a - to a depth of H = 60 m of immersion of underground structures of the drainage system: b - monitoring results (1,2,3 - respectively during construction and operation for the period 1975-2022; 3 - active zone of interaction of an underground structure with a soil massif).

2 Restoration of underground water-carrying communications in an unstable environment

2.1. Modeling of the interaction of water-bearing communications with the ground under external influences

During the interaction of water - bearing communications with heterogeneous soils , deviations of the structure from the vertical axis occur under external influences (see Fig.4). Under external influences, sections of the tunnel are in a different stress-strain state (SSS). Numerical modeling determines the maximum permissible stresses that do not cause a violation of the structural safety of the structure. Numerical modeling for determining deformations and displacements of structures in the ground environment is performed using geotechnical software systems PLAXIS 2D, 3D, PLAXIS-tunnels. The stress-strain state (SSS) and the maximum permissible stresses that do not cause a violation of the structural safety of the structure are calculated using the design programs ROBOT-str, MIDAS IT [11,12,13].

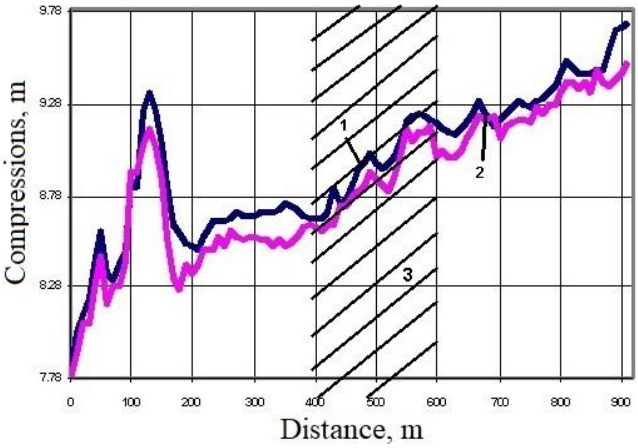


Fig. **4**. Geological section of engineering and geological conditions: monitoring results (1,2,3 - respectively during construction and operation for the period 1975-2022; 3-active monitoring zone).

The structural safety of underground wastewater disposal facilities is influenced by the impact of external, static and dynamic influences.

A system for assessing the dynamic impact of transport was used by studying the oscillatory process using a set of sensors and recording equipment [14,15,16].

The oscillation frequency is set from 15 to 35 Hz and the amplitude is up to 35-70 microns. For the above-shown ground deposits and the corresponding level of dynamic impacts, the decrease in strength characteristics of C and φ is up to 35% and 17%, respectively. Geotechnical methods of protecting underground structures from dynamic and static impacts and vibration protection measures, such as the use of carbon fiber reinforcement and lining technology for internal structures, are proposed.

2.2. Modeling of maximum permissible impacts on underground structures and justification of protection methods

The choice of methods was carried out on the basis of computer modeling and the choice of constructive solutions. The maximum permissible tensile stress in the load-bearing shell was taken as an assessment of the structural safety of the structure (Fig. 6).

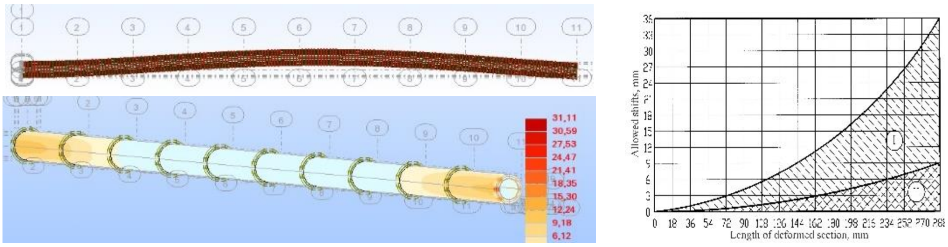


Fig. 5. A fragment of the results of modeling the interaction of an underground structure with a host soil environment (a) and the displacement of a linear structure under the influence of an external static load (b): 1,2- the boundaries of the structural safety corridor, respectively, before and after structural reinforcement.

The developed geotechnological methods of ensuring structural safety were applied at wastewater disposal facilities. The permissible values of external influences were determined by numerical modeling using software systems for geotechnical and design calculations. The Figure 6 shows fragments of work on the structural protection of a linear underground structure associated with man-made impacts. The project provided for monitoring of the tunnel and the structure of the geomass [17,18,19,20,21].

Calculations of stress-strain behavior of a tunnel sewer made with account of an internal hydrostatic pressure show the picture of violation of structural safety of the tunnel. At the observed overflow of the tunnel sewer up to the water level H = 30 m the hydrostatic pressure P=3000 MPa is added to the calculation scheme.

When hydrostatic pressures are applied to the internal lining of the tunnel the extreme values of tensile stresses including hydrostatics reach sXX=102, 66 kg/cm^2. These values considerably exceed the admissible values in tubings and internal lining, that leads to occurrence of cracks in concrete of the tunnel structures, damage of joints and waterproofing.

When a tunnel operates at a forced flow, hydrostatic pressures are applied to the tunnel lining. In this case extreme values of tensile stresses in tubings with hydrostatics reach the values, which considerably exceed admissible values, it should be taken into account in order to select structural reinforcement of a tunnel at its reconstruction (see Fig. 6).

The main requirement to taking protective measures was to use such a technology which would allow carrying out repair works in conditions of continuous transportation of sewage discharge.

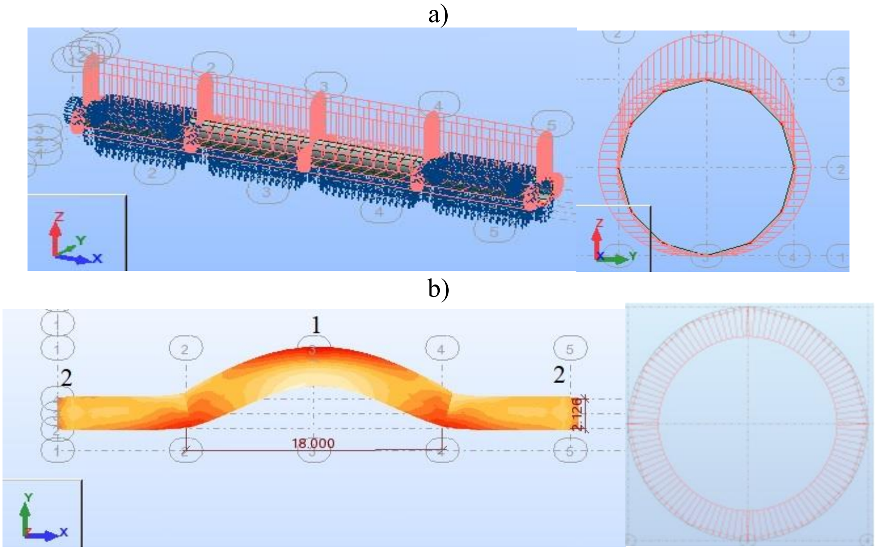
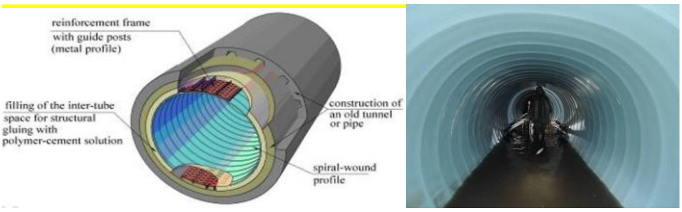


Fig. 6. A fragment of calculation of stress-strain state of a tunnel sewer, 18-m displacement at the hydrostatic action (P=3000 MPa): a) with loads and elastic thrust; b) areas of beyond-limit strain-stress behavior of a tunnel: 1- in the middle and 2- at ends of a displaced.

The technology of sanitation using the method of coiling was used for repair and recovery of bearing capacity of the tunnel. The scope of workflow included: cleaning the tunnel and preparing its surface; structural gluing of concrete lining and tubing lining through jetting SikaDur material; strengthening the crown surface by structural reinforcement carbon plastic SikaWrap; facing the tunnel surface with PVC coiling profile; jetting polymer-cement slurry (Pcomp.= 65MPa) in inter-pipe space for structural gluing PVC envelope with the tunnel structure. The fragments of operation are shown in Fig.7.

Protection from man-made impact of the tunnel



The composition of the complex structural protection of an infrastructure facility

Structural protection of the infrastructure facility is provided for 50 years or more

Fig. **7**. Fragments of the implementation of a constructive solution to ensure the structural safety of an infrastructure wastewater disposal facility for 50 years or more.

The developed geotechnical methods of protecting the structural safety of underground structures are widely used at the facilities of the drainage system and are successfully applied at the facilities of the Oktober Railway branch of RZD during the reconstruction of culverts under embankments in the conditions of a watercourse [22,23].

3 Practical significance and conclusions

On the basis of studying the processes of interaction of underground On the basis of studying the processes of interaction of underground drainage structures and water-carrying communications with unstable soils under various non-stationary energy and environmental impacts, factors leading to a violation of their structural safety were identified.

A comprehensive approach has been developed to the selection and justification of methods for the protection of underground structures that have been operated for a long time in difficult soil conditions, taking into account the increasing anthropogenic impact.

The causes and mechanism of defects in tunnel structures operated under conditions of wastewater transportation have been identified. The necessity of primary protection of sewer tunnels, which form the basis of the system of underground sewer structures that ensure the reliability of the functioning of the infrastructure of large cities, from natural and anthropogenic influences is shown. .

A method and algorithm for calculating the interaction of soil and structures are proposed that allow modeling the processes of interaction of the tunnel shell with the ground environment and predicting the parameters of their joint operation and protection methods. recently proposed diagnostic methods based on an extensive study of the operation of sewer tunnels in conditions of soft soils and intense anthropogenic impacts can be used to assess the technical condition of facilities operating under specific impacts.

The experience of application of geotechnical methods of protection of underground aquifers on real objects located in the conditions of unaccounted soils is described. The unique experience in the application of geotechnical methods for the protection of underground infrastructure facilities is recommended for practical use in order to increase the reliability of the functioning of underground aquifers.

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The experience of applying geotechnical protection methods of underground water-bearing structures on real objects located in conditions of unaccountable soils is described. The unique experience of applying geotechnical methods to protect underground infrastructure facilities is recommended for practical use in order to increase the reliability of the functioning of underground water-carrying structures in difficult ground conditions and having a low level of structural safety.

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