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# Experience in strengthening foundations and foundations on technogenic soils

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**Abstract.** The article discusses modern methods of strengthening foundations on artificial bases that have received excessive precipitation and rolls. In the course of studies, it was found that the use of bored piles allows transferring the load to the underlying reliable foundation at any depth, and cementing the foundation soil contributes to improving the physical and mechanical characteristics of the backfill soil.

## 1 Introduction

Today, in the conditions of active intensification of the construction of new industrial and civil construction facilities, it is increasingly necessary to develop territories that in the past were considered unsuitable for construction due to difficult engineering and geological conditions [1]. By the current regulatory documentation, engineering and geological conditions are considered difficult in the following main cases:
1. The construction site is located within several geomorphological elements of different genesis, and the surface of the construction site is strongly dissected (ravines, gullies, hollows, slopes, etc.);
2. In the active thickness of the soil there are more than four layers of different lithology, the thickness of which varies dramatically. The occurrence of the layer is characterized by wedging and lenticular stratification;
3. The soils composing the site are characterized by a significant degree of heterogeneity in physical and mechanical parameters;
4. The groundwater horizon is not sustained in terms of stretch and power. There is a complex alternation of aquiferous and water-resistant rocks on the site. The pressure of underground water and their hydraulic connection vary along the stretch;
5. Geological and engineering - geological processes that negatively affect the conditions of construction and operation of buildings and structures are widespread;

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5. Geological and engineering - geological processes that negatively affect the conditions of construction and operation of buildings and structures are widespread;
6.Specific soils (organo-mineralogical, loess, swelling, saline, subsidence, karst, etc.) are widespread in the field of interaction of buildings and structures with the geological environment, which have a decisive influence on the choice of design solutions, construction, and operation of objects [2-4].

Construction in these engineering and geological conditions is associated with certain risks (the possibility of the development of excessive uneven sediments and rolls), which require the adoption of reliable design solutions that ensure the subsequent safe operation of facilities.

At the same time, it is often assumed that unsuitable soil is excavated from the base and replaced with stronger, less compressible soils (often sandy), but any violation of the work technology (insufficient compaction of the backfill soil, non-compliance with the size of the soil fraction, the inclusion of frozen fractions, abundant soaking during the work, etc.) leads to a deterioration of the physical and mechanical characteristics of the soil of the filled artificial bases laid down by the project, which is usually detected already during operation, and it requires their further operational strengthening [5-8].

One of the most widely used methods of strengthening artificial foundations is the use of piles, which allow cutting through the thickness of weak soils and transferring the load from the structure to a reliable soil base. In modern conditions, drilling-injection piles are increasingly being used [9, 10]. The main directions of application of drilling-injection piles are strengthening of existing foundations and bases, use as foundations and fences during construction next to previously erected capital construction objects, during the reconstruction of existing buildings and structures (extension, superstructure, arrangement of basements, etc.), construction in difficult ground conditions, use as anchor fasteners, etc. Currently one of the best methods for CFA piles is a German technology such as "Titan" [11], domestic analog “Atlant” [12, 13], and "Normal" [6, 7] based on the use as the core of a pile of rods of high-strength hollow tubes connected by joints, which provide high strength and tightness of the connection.

Another direction of strengthening artificial bases is to increase their physical and mechanical characteristics by pumping a mobile cement / sand-cement mixture. This method allows you to fill the pores that are present in the soil thickness, thereby reducing its compressibility, as well as increasing its strength characteristics. One of the methods of applying high-pressure injection is the crimping of the ground base and the restoration of the contact layer at the "foundation-base" boundary [5].

## 2 Materials and methods

In this paper, various options for strengthening structures that have received excessive precipitation and rolls as a result of poor-quality work on the installation of an artificial foundation, violations of the technology of work, deviations from the design decisions made are considered.

One of such objects is fiberglass tanks sewage pumping stations (SPS) used for the removal, collection, and pumping of surface water at the airport in Tobolsk. The structure is a system of tanks (fiberglass tanks) installed on a pile-plate foundation. At the level of the planning surface, support necks are resting on the unloading reinforced concrete slab. The unloading plate is based on the backfill soil (fine, dense sand). The general view of the SPS tanks is shown in Figure 1.

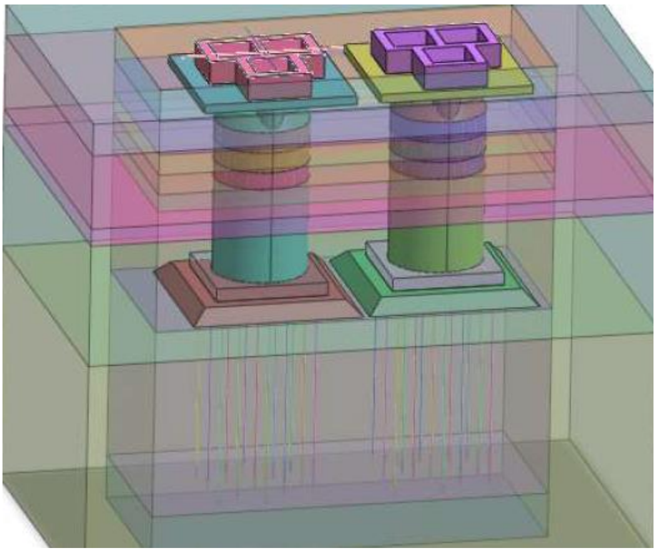

**Fig. 1.** Three-dimensional model of SPS tanks.

According to the results of determining the technical condition of SPS fiberglass containers, their damage (the formation of folds and cracks, violation of tightness) was established at the level of the location of the support necks. It was revealed that in the zones of concentration of local stresses (zones of transitions of the spherical tank cover into the necks), due to an additional non-normalized (unaccounted for) load from the discharge plate, local destructions (ruptures) of the structures of fiberglass tanks occurred, since the compensation layer of backfill sand did not enter into operation. Also, the formation of the identified defects was affected by the effect of excessive lateral pressure as a result of the abundant inclusion of dusty particles in the backfill material.

In order to exclude the subsequent formation of defects, it was necessary to strengthen the structure, which was carried out in two stages:

- at the first stage, it is necessary to cement the base to fix the backfill soil in the space between the tanks and the sheet pile fence. Increasing the strength and deformation characteristics will reduce the lateral pressure on the tanks and prevent their possible destruction.
- at the second stage, transfer the load from the level of the discharge plate of the tanks not to the neck of the tank, but to the soils lying below the bottom of the tanks by transferring the load from the own weight of the base plate and the calculated load from the air vehicle to the drill-injection reinforcement piles (DIRP).

To ensure the operational reliability of the structure, the design bearing capacity of the piles should be 400-500 kN. The piles were installed in an array of fixed soil. The length of the piles was 10-13 m with an average diameter of 0.25 m.

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Another similar object is the operator's office building at gas station No. 385, located at the address: Tyumen, Zapadnosibirskaya str., 37. Structurally, the building is one-story, rectangular in plan with dimensions in the axes of 12,5x8,0 m. The walls are made of a metal frame filled with expanded clay blocks and insulated with mineral wool slabs; the roof is single-pitched from profiled sheet; the foundation is in the form of a monolithic reinforced concrete slab 0.3 m thick. The general view of the object is shown in Figure 2.

**Fig. 2.** General view of the gas station.

According to the results of the survey, significant, randomly located gaps (cavities) between the bottom of the slab structure and the top of the ground base with a value of up to 0.1 m were revealed under the slab. The thickness of the foundation plate does not correspond to the design values.

The values of the actual relative precipitation of the slab foundation exceed the maximum permissible values recommended by the norms by up to 2.5 times.

Since the bearing layer of soil for supporting the pile is located at a depth of 9.0-10.2 m, the pile length of 10.0 m with an average diameter of 0.2 m was adopted.

The main reason for the occurrence of excessive uneven sediments of the foundation plate is the uneven compaction of the backfill soil (mainly dusty sand with the inclusion of loam) in time, significant depth, heterogeneous in physical and mechanical properties of the bulk soil thickness, which is confirmed by the presence of a significant number of different, randomly located voids between the foundation plate and the base. In this regard, the behavior of the foundation plate in the future, without measures to strengthen the base and foundations, was unpredictable.

To ensure the full inclusion of the slab foundation in joint work with the foundation, it was decided to restore the contact layer "foundation – ground foundation" by injection of cement mortar, and to eliminate the development of foundation sediments and their unevenness, to strengthen the foundation of the Object by the device of drilling-injection piles.

## 3 Results and discussion

To determine the bearing capacity of piles made using the Atlant technology to strengthen the structures of fiberglass SPS tanks, the piles were tested with a static indentation load by GOST 5686. The scheme of the test installation is shown in Figure 3.

**Fig. 3.** Diagram of the test facility.

Loading was carried out with a hydraulic jack of the DGA150P150 brand. The vertical movements of the tested piles and anchor piles were measured by indicators of the hourly type of modification ICH 50,000 PS of accuracy class 1 with a division price of 0.01 mm.

The test results are shown in Figure 4.

In the process of restoring the contact layer on the operator unit of the gas station, to exclude the release of cement mortar during injection outside the spot of the foundation plate, a sheet pile fence was installed along the perimeter at a distance of 0.5 m from the face of the plate to a depth of about 3.0 m. In the process of feeding the cement mortar with grippers into the soil mass, an excess pressure was created in the region of 150-200 kPa, which made it possible to lift the foundation plate and correct its unevenness. The maximum height of the plate was 0.2 m (Fig. 5).

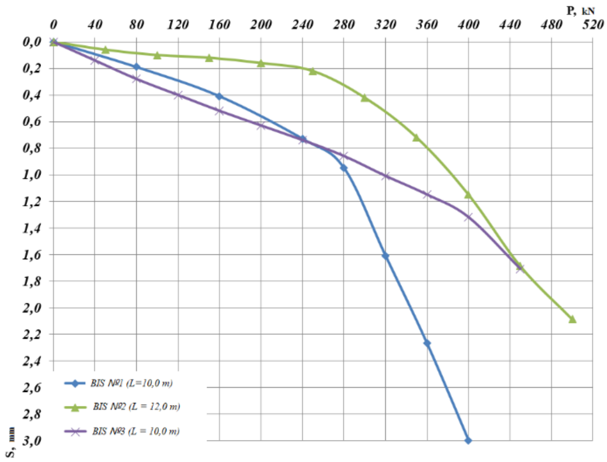


**Fig. 4.** Load-draft graph for the tested piles.

**Fig. 5** The process of eliminating uneven precipitation of the foundation plate in the process of soil injection.

## 3.1 Main conclusions

The results of control tests of drilling-injection reinforcement piles for static indentation load arranged in the discharge plates of fiberglass tanks SPS are presented in Table 1.

**Table 1.** Results of testing of piles for a pressing load.

| | Fd,project, kN | Fd,fact, kN | S, mm |
|---|---|---|---|
| DIRP 1 | 400 | 400 | 3.00 |
| DIRP 2 | 500 | 500 | 2.08 |
| DIRP 3 | 400 | 460 | 1.74 |

The purpose of control tests of drill-injection piles with static indentation loads was to confirm their design load-bearing capacity, so the tests were stopped when it was reached. The pile sediment when reaching the reference value of the load value did not exceed the normalized 20 mm, which corresponds to clause 8.2.4 of GOST 5686-2020.

Analyzing the graphs presented in Figure 5, we can conclude that all piles have the same nature of work and work in a similar range of loads and deformations, have a high bearing capacity on the ground [14].

All graphs have two linear sections of work, which are mainly due to the compression of the material of the trunk of the drill-injection piles of reinforcement. Also, the predominant compression of the pile trunk material in comparison with the shear sediment on the ground is evidenced by the fact that after removing the load, the residual sediment of the pile was about 0.6 – 1.0 mm, which is only 0.30 – 0.35% of the total sediment of the pile.

## 4 Conclusion

Since often the construction of industrial and civil facilities in difficult engineering and geological conditions involves the excavation of unsuitable soil and its replacement with more reliable layers (often sandy), any violation of the work technology (insufficient compaction of the backfill soil, non-compliance with the size of the soil fraction, the inclusion of frozen fractions, abundant soaking during the work, etc.) leads to a deterioration of the physical and mechanical characteristics of the backfill soil laid down by the project, this can eventually cause uneven precipitation of buildings and structures, as well as the development of rolls.

The use of such reinforcement methods as the device of drilling-injection piles and cementation of the foundation soil allows to improve the physical and mechanical characteristics of the backfill soil (in the case of soil cementation) or to transfer the load to the underlying reliable foundation soils regardless of the depth of their location (in the case of drilling-injection piles).

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