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Selection of Effective Technologies for Strengthening the Soils of the Foundation of Small Structures in Challenging Conditions

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Abstract: This article analyzes technologies for strengthening small-structure foundations and improving soil properties in challenging conditions. After comparing current methods used in hydraulic engineering, soil column construction was selected as the preferred approach. This technology offers reliability and profitability while minimizing risks in challenging ground environments.

1 INTRODUCTION

In recent years, increasing water scarcity has led to greater emphasis on designing, constructing, and rationally using small structures in challenging engineering-geological contexts. According to the Ministry of Water Resources, small structures now outnumber large ones in the republic. Ensuring the long-term safe operation of these small structures is a pressing concern. To meet this challenge, stakeholders should systematically review both positive and negative global experiences in hydraulic engineering and implement best practices accordingly (Paluanov, 2022).

It is essential to recognize factors that inevitably cause the condition of structures to deteriorate, even when used correctly. These include aging materials, weakened foundations, and changes over time in strength, water resistance, and other properties. When needed, plan for major repairs, reinforcement, or replacement of outdated structures with modern materials.

Soils that quickly lose their properties under the influence of external factors capable of deformation are widespread in the Amudarya River delta. The depth of these soils ranges from several centimeters to tens of meters and even more meters. In such cases, insufficient assessment of the properties of deformable soils leads to the loss of strength and stability of the foundations of small structures, which can subsequently lead to catastrophic consequences. Such cases were very common in the practice of hydraulic construction and caused significant damage to socio-economic sectors (Paluanov, 2023; Paluanov, Mamatkulov, Gadaev, Saidov, 2024; Sadiev, Makhmudov, Makhmudov, Rustamov, Saydullaev, Alikabulov, Pirnazarov, 2023).

The reliability of the foundations of small structures and the reduction in the cost of their construction work largely depend on the correct assessment of the properties of the soils in the foundation, the effectiveness of the chosen technological methods and dimensions, and the quality of these works.

2 MATERIALS AND METHODS

A complex multi-layered soil layer was identified at the base of the small structure: layer 1 - sandy loam (thickness 3.8 m), characterized by a low deformation modulus (E=5 MPa) from the surface; layer 2 - loamy loam (thickness 5.8 m), also having a low load-bearing capacity (E=4 MPa); layer 3 - dusty sands

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(thickness 4.5 m), critical layer. It lies at a depth of 9.6 m from the surface; layer 4 is semi-solid clay (thickness 1.0 m). It is a relatively strong layer, but its low power does not allow it to be considered a reliable distribution layer (Figure 1). The 3rd layer has floating properties, which is the main problem in designing small structures in hydraulic engineering practice (Paluanov, 2023).

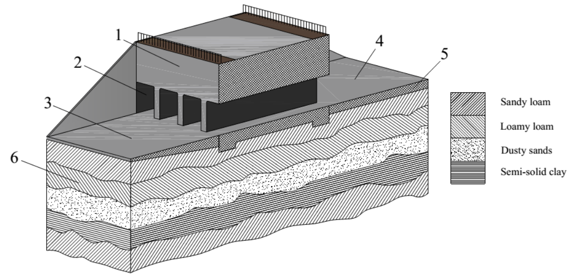

Figure 1: Cross-section of a small structure located in complex soil layers: 1-body of the concrete structure; 2-water passage gap; 3-upper pool; 4-lower pool; 5-structure flutbet; 6-multilayer base.

The groundwater level is in the range of 4.5-6.4 m, which directly affects the water-saturated soil. This means that part of the third layer (approximately the upper 0-1.9 meters) is above the groundwater level, and its main part (~2.6-4.5 m) is below the water level, which determines its floating properties under dynamic influence.

In the third layer (thickness 4.5 m), located at a depth of ~3.8+5.8=9.6 m from the surface, dusty sands with floating properties are represented. After construction, the structure will be constantly filled with water, which will lead to complete water saturation of all soils and activation of floating properties.

Soils and groundwater are aggressive against ordinary concrete, which requires the use of sulfate-resistant cements and special protective measures.

A float is a water-saturated fine-grained sand (dusty), which, upon dynamic impact or opening, transitions to a flowing state. This leads to:

- sharp loss of soil load-bearing capacity;
- large and uneven settlement of the structure;
- flooding of the pit and its flooding during development attempts;
- difficulties in digging piles and other foundation elements.

Reinforcement of a section composed of dusty sands with floating properties to ensure the stability and minimal sedimentation of the designed structure.

Based on the above, it is important to choose effective and economical technologies to ensure the strength and increase the reliability of the foundation of a small structure (Kosichenko, Bayov, 2022; Shchedrin, Kosichenko, Baklanova, Bayov, Mikhailov, 2016; Lapin, 2021; Combefort, 1971).

3 RESULTS AND DISCUSSION

For the conditions of the site, methods that allow stabilizing the float without removing it are considered (Ibragimov, Semkin, 2012; Mangushev, Usmanov, Lanko, Konyushkov, 2012; Broyd, 2004; Malinin, 2009; Rubtsov, Kutilin, Fateev, 2005).

Silication (Chemical fixation)

Principle of the method. Chemical solutions (for example, sodium silicate "liquid glass" and calcium chloride) are pumped into the floating layer through injectors (pipes) under pressure. Solutions react in soil pores, forming a strong waterproof gel of silicic acid, which cementes sand particles.

Application technology. Drilling injection wells at a distance of 0.8-1.2 m to the depth of the float and below. Immersion of injectors. Sequential pumping of solutions in a given sequence. Formation of columns or a continuous mass of fixed soil in the soil.

Benefits. High efficiency: allows for the creation of a strong and waterproof mass directly in the float zone. Minimal dynamic impacts: The process is silent and does not cause vibrations. The ability to work in tight conditions. Increasing not only strength but also water resistance, which is crucial for the float.

Disadvantages and risks. High cost of chemical reagents. Aggressive environment: it is necessary to use chemical solutions resistant to existing soil aggression or apply additional inhibitors. Control complexity: the distribution radius of solutions can be uneven. Environmental aspects: strict control over the distribution of chemicals is necessary.

Profitability. The method is expensive, but in this case, it can be economically justified, as it allows for avoiding deep pits and complex earthworks. The cost is heavily dependent on the volume of cemented soil and the price of reagents.

Cementation (Smolization)

Principle of the method. Similar to silicatization, but finely dispersed cement solutions (microcements) or synthetic resins are used as reagents. Microsements are capable of penetrating the fine pores of dusty sands.

Application technology. The technology is similar to silicatization. Careful selection of the solution composition and injection pressure is required.

Benefits. High strength of the fixed soil (especially when using resins). Relative environmental safety when using cement mortars. Good compatibility with the "wall in the ground" or splinter fence device.

Disadvantages and risks. The cost is very high, especially for resin compositions. For dusty sands, the application of special microsegment is required, which makes the process more expensive. Aggressive environment: cement mortars must be on sulfate-resistant cement, which increases the cost.

Profitability. The least profitable method for large volumes due to the high cost of materials. It can be applied locally, for point-based reinforcement of the most vulnerable zones.

Jet Grouting

Principle of the method. A special monitor (hydraulic cutter) on the drilling rod delivers a stream of cement solution into the soil under ultra-high pressure (300-600 atm.), which simultaneously destroys and mixes the soil with the binder. Columns or panels are formed from clay cement.

Application technology. Directional well drilling. Supplying a cement mortar jet while simultaneously raising and rotating the rod. Formation of columns of a given diameter (up to 2.5-3.0 m).

Benefits. A radical solution to the problem: the float is not reinforced, but replaced with a new artificial material (soil cement). High predictability and quality control: column parameters (diameter, strength) are strictly controlled. Creating continuous underground walls (for enclosing the pit) and a continuous base for the slab. The possibility of using sulfate-resistant cement to protect against aggressive environments.

Disadvantages and risks. The cost of equipment and work is very high. Large volume of by-products (slag): The resulting ground-cement pulp requires removal and disposal. Requires significant work space.

Profitability. Despite its high initial cost, the method can be the most reliable and justified in the long term, as it completely eliminates the risk associated with the float. Saving is achieved by reducing work time and increasing reliability.

Device of deep supports with float passage

Principle of the method. Instead of reinforcing the float throughout its entire volume, it is driven by drill-loaded piles or screw piles until it rests on the underlying strong layer (in this case, semi-solid clay or the next layer).

Application technology. The casing pipe is lowered through the float, preventing it from entering the well. After concreting, the pipe is extracted. The use of sulfate-resistant concrete is mandatory. Screw piles: The piles are screwed into the ground, minimizing the dynamic impact on the float.

Benefits. Transfer of load to deep, stable soil layers. Relatively well-developed and reliable technology. For screw piles - high installation speed and absence of vibration.

Disadvantages and risks. Difficulty of submersion through a drift: complications may arise (wellbore wall collapse, absorption of drilling fluid). The need for careful monitoring of the quality of pile concreting. Screw piles: in an aggressive environment, reliable anti-corrosion protection is required.

Profitability. It is often the most profitable solution. The cost of installing a pile field, even considering the complex conditions, can be lower than the cost of fully securing the float. Allows for clear prediction of carrying capacity and precipitation.

Device of soil piles (soil concrete columns) using Deep Soil Mixing technology

Principle of the method. A special device with rotating blades (mixers) is immersed in the ground while simultaneously supplying the binding material (cement mortar). The soil is thoroughly mixed with cement, forming a high-quality column.

Application technology. High. It is widely used for strengthening weak soils, including floats.

Benefits. High quality and homogeneity of the resulting columns. Absence of vibration and noise during operation. Possibility of using sulfate-resistant cement.

Disadvantages and risks. It requires powerful and specialized equipment. High cost.

Profitability. Average. Comparable to jet cementation, it can be more efficient in terms of workload.

Full or partial replacement of soil

Principle of the method. Excavation of weak floating soil within the zone of active influence of the foundation and its replacement with layer-by-layer compacted non-bubble material (large or medium sand, gravelly soil, sand-gravel mixture).

Application technology. Very low, practically impossible. The floating layer lies at a depth of about 9.6 meters. Developing a pit of such depth under floodplain conditions and high groundwater levels will require a complex spunt barrier and continuous water reduction, which is economically inefficient and extremely dangerous. The walls of the pit will constantly collapse. Direct removal of weak soil and creation of an artificial foundation with predictable and high strength characteristics.

Benefits. Fully solves the float problem within the replaced volume. The result is predictable and reliable. Does not require highly specialized equipment (excavators, bulldozers, vibrating compactors are required).

Disadvantages and risks. Depth of occurrence: the main mass of the float lies at depths from ~3.8 m to ~8.3 m. Developing a trench of such depth in water-saturated soils is extremely complex, dangerous, and requires effective water drainage and spunt barriers to prevent collapses and wall flooding. Water reduction: Intensive water pumping can lead to the removal of small particles and sedimentation of surrounding areas, including the foundation of existing highways. Large volume of work: it is necessary to extract and dispose of ~150 m2 · 4.5 m = 675 m^3 of weak soil, then bring in and compact the same volume of quality material. Problem of disposal: the salted float requires a special site for disposal.

Profitability. Cost: very high. Costs consist of: constructing a splinter fence along the perimeter, continuous water reduction, excavation and disposal of soil, and importing and compacting new material. Efficiency/cost: low for a given depth. The method can only be considered if it is necessary to eliminate a very small area of the float, which is not applicable in our case.

Based on the above, the methods can be divided into three groups:

Group 1: Highly effective and recommended

- Jet Grouting;
- Deep Soil Mixing.

Group 2: Applicable but with significant limitations

- Device of deep supports (swaves).

Group 3: Not recommended for these conditions

- silicatization, cementation, soil replacement.

4 CONCLUSIONS

As the main method for strengthening the float area for a small structure, the technology of Deep Soil Mixing should be adopted.

Further actions:

1. Clarifying surveys: Conduct additional engineering and geological surveys specifically in the float zone to determine its precise characteristics (granulometric composition, filtration coefficient).

2. Test strengthening: At the site, away from the main structure, it is mandatory to perform a test installation of 2-3 soil-concrete columns using Deep Soil Mixing technology.

3. Laboratory tests: Select soil concrete cores from the test columns and test them for compressive strength and chemical resistance in aggressive environments. This will allow for the accurate selection of cement grade, mortar composition, and production parameters.

4. Design: Based on the obtained data, perform a detailed calculation:

- column diameter and pitch;
- depths of their immersion;
- composition of the binder.

A comprehensive approach to applying this technology ensures reliability, longevity, and maximum profitability in design, minimizing risks associated with complex ground conditions.

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