Bearing capacity of bored piles made with polymer drilling mud

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Abstract. The main results of the work on the analysis of the possibility of using polyacrylamide drilling muds for the installation of drill piles, barrettes and slurry walls in sandy soils are presented. The results of the study of the possibility of solutions to keep the walls of boreholes from collapse, laboratory studies of the effect of polyacrylamide solutions on the shear strength of soils, as well as the results of field tests of piles with static pulling load are reflected.

1. Introduction

To ensure the stability of the borehole walls in the case of bored piles, barrettes and slurry walls in the soil, thixotropic drilling muds are used. As such a decision, water-based solutions and, in particular, clay (bentonite) solution have found wide application. At the same time, along with the undoubted advantages of bentonite slurry, such as the possibility of using in most types of soils, ease of use, relative cheapness, etc., there are certain disadvantages that prompted the search for alternative decisions to retain the walls of boreholes and entrapments. A significant disadvantage of using a bentonite slurry is the need to have a bentonite plant on the site, in which the slurry is formed and regenerated. Often, when constructing foundation pits in the existing dense housing, there is simply no place for such a plant. Another important drawback of bentonite slurry is the complexity of its disposal since after using the slurry turns into a gel-like mass and, most importantly, the drying process of such a mass becomes long and laborious, including concerning export and disposal. Unlike wet and silty soils, which are enough to mix in a certain proportion with soil or sand or just leave for a while to dry naturally, bentonite gel requires certain chemical conditions and a significant layer of soil/sand for mixing to remove moisture from it, as well as and large areas for this. For this reason, the disposal of the used bentonite slurry can be very laborious and costly.

In this regard, the search for an alternative slurry led the researchers to first use polymer additives to the bentonite slurry, which improve its properties and then to completely replace it with polymer solutions. It was required to select polymer solutions that have all the positive properties of a bentonite slurry but do not have their disadvantages.

A breakthrough in the use of polymers in geotechnical construction occurred in the early 1990s when partially water-soluble polyacrylamides began to be used in the construction industry in the United States, and then it spread from North America to other parts of the world [1]. Currently, water-soluble synthetic polymers, such as polyacrylonitrile, polyacrylamide, carboxymethylcellulose, copolymer, find more and more widespread use, which, however, is constrained by insufficient knowledge of various compositions in different soil conditions. In the construction industry, polyacrylamide drilling mud is increasingly used as a drilling one [2 to 8].
According to the Big Russian Encyclopedia [9], polyacrylamide is a synthetic polymer of the general formula \([-\text{CH}_2-\text{CH(CONH}_2]-\text{in}\). This amorphous white substance, density 1302 kg/m\(^3\), molecular weight \(2 \times 10^5\)–\(6 \times 10^5\), in contact with water forms a gel of high viscosity. Anionic polyacrylamides are used as drilling muds, which are negatively charged polymers that allow them to attract particles of soil, clay or sand.

In NIIOSP named after N.M. Gersevanov, a study is being made of the possibility of using polyacrylamide drilling muds for piles, barrettes and slurry walls. Research of the physical properties of polyacrylamide solutions and their ability to hold the walls of the trench is carried out; laboratory studies of the effect of polyacrylamide solutions on the strength properties of sandy soils and their interaction with concrete. Also, field studies were carried out on the possibility of using polyacrylamide solutions in the conditions of real construction sites, as well as comparative tests of bored piles made with the use of polymer and bentonite [10, 11].

2. Study of the physical properties of polyacrylamide solutions
In the course of laboratory research, polyacrylamides used as drilling solutions were used: BAUER SlurryLTP, LTP 709, LTP 703 and Super Mud from PDSCo; and also polyacrylamide of Russian production Polyflok (TU 2414-002-74301823-2007) of the following names: 1520, 1505, used in water supply and water treatment systems. All samples are presented in the form of a white powder. According to the results of the chemical analysis performed at the Moscow State University named after M.V. Lomonosov, all investigated polymer solutions belong to anionic polyacrylamides with a degree of hydrolysis from 5 to 20 [10].

Mixing of polyacrylamide with water occurs within a few minutes, the complete stabilization of the viscosity of the solution takes about an hour. The consumption of dry polyacrylamide is relatively small: 1 ... 10 kg/m\(^3\), the density of the finished solution slightly exceeds the density of water and is: 1.001 g/cm\(^3\). With an increase in the concentration of the polymer in the solution, the viscosity of the solution increases sharply, which makes it unsuitable for practical use (figure 1).

When mixing a polyacrylamide solution with a concrete mixture, there is a sharp decrease in the mobility of the latter. When the concentration of polyacrylamide is more than 1%, delamination of the concrete mixture is observed.

![Figure 1. Graph of the change in the viscosity of a polymer solution with an increase in the concentration of polyacrylamide.](image)

3. Studies of the ability of polyacrylamide solution to hold the walls of the trench
The study of the ability of polyacrylamide solution to keep the walls of the sand trench from the collapse was carried out both in the laboratory and in the field (see section 5).

In laboratory conditions, studies were carried out in a transparent tray 80 × 40 cm in size, divided into parts by a movable partition (shutter) [10]. Coarse or medium-sized sand was placed in one of the parts, drilling mud was poured into the other, after which the movable shutter was raised. As a result of trough tests, it was found that the stability of the trench wall made of medium-sized sand is ensured at a conditional viscosity of at least 80 s (according to the Marsh funnel), for coarse sand this value increases to 120 s. At lower values of viscosity, the walls collapse (figure 2). In this case, the collapse
does not occur immediately, but as the polymer solution penetrates the sand, that is, as the horizontal pressure gradient decreases. At the same time, the key characteristics that determine the effectiveness of the retention of the trench walls are the shear resistance of sandy soil particles, which depends on the hydrodynamic pressure of the polymer solution on the trench walls and on its viscosity, as well as the filtration coefficient and the degree of soil moisture, which determines the dynamics of change in the pressure gradient.

A similar substantiation of the stability of the trench walls when using polymer drilling mud is given in [12].

![Figure 2](image1.png)

**Figure 2.** The development of the collapse of the trench wall in time during tray tests of the solution 1520 at a relative viscosity of 40 s and sand of medium size (at the moment of lifting the curtain (a), after 15 minutes (b), after 30 minutes (c)).

4. Laboratory studies of the effect of polyacrylamide solutions on the strength properties of sandy soils

To assess the degree of influence of polyacrylamide solutions on the strength properties of sandy soils in laboratory conditions, a series of comparative tests were performed on a single-plane cut of sands impregnated with a polymer solution and sands impregnated with distilled water.

Tests of soil samples were carried out according to the scheme of consolidated-drained (slow) cut.

During the tests, three types of sand were used according to the particle-size distribution (coarse, medium and fine), each of which was compacted to a dense, medium density or lose state. Based on the results of comparing the results of the tests of soil samples impregnated with a polymer solution and distilled water, it was concluded that for sands of large and medium-size, the difference in the obtained values does not exceed the statistical scatter of values, that is, the presence of a polyacrylamide solution does not significantly affect the strength properties sands of various sizes and densities. In the case of fine sands, the presence of a polyacrylamide solution increases the shear resistance by an average of 25% [11].

To assess the effect of the polyacrylamide solution on the strength of the concrete-soil contact, a series of shear tests were performed, in which the samples were displaced along the concrete surface (figure 3), previously similar tests were performed by Ter-Martirosyan A.Z., Sidorov V.V. и Isaev O.N., Sharafutdinov R.F. [14] in the study of the strength of soil contact with underground structures.

![Figure 3](image2.png)

**Figure 3.** Scheme of testing the strength of concrete-soil contact.

Based on the comparison of the results of tests carried out on soil samples impregnated with a polymer solution and distilled water, it was concluded that the difference in the obtained values does...
not exceed the statistical scatter of values. The presence of a polyacrylamide solution does not significantly affect the strength properties of the concrete-sandy soil contact.

5. Field studies of the possibility of using polyacrylamide solutions

To confirm the conclusions obtained from the results of tray tests, field tests were carried out on the use of a polymer solution when installing bored piles in sandy silty soils. Experimental studies were carried out at the construction site of a modern shipbuilding complex located at the Korabelnaya st. in St. Petersburg, on the territory of the Severnaya Verf plant, in June 2018. During the pilot work, BAUER LTP 709 and SuperMud polyacrylamide drilling muds were used, under the protection of each of which 3 piles were made. The boreholes filled with the solution were kept for 1, 36 and 72 hours until concreting.

The boreholes was drilled to -3.00 from the ground level under the protection of the inventory casing, and below, to a depth of -5.70, using polymer drilling mud. After the completion of drilling, the bottom of the well was cleaned with a bucket and the polymer solution was poured to the ground level. After the completion of drilling, the well depth, the level and indicators of the solution at the level of the wellhead and bottom of the well were monitored every hour. After maturing the required time, a steel frame was installed in the well and concreting was carried out using a concrete pipe from the bottom up.

According to the results of the experiment, it was found that the density and pH did not undergo significant changes from the moment the solution was made to concreting and amounted to 1 g/cm³ and pH = 6.

The viscosity of the solution actively decreased from 120 to 80 s during drilling, probably as a result of mixing with groundwater, and after the completion of drilling operations within 72 hours it decreased slightly, on average by no more than 10%.

The percentage of sand in the solution was actively decreasing within 40 minutes from the moment of completion of drilling operations to a value of 0.1 ... 0.2% by weight of the solution.

After the completion of concreting, the continuity of the resulting concrete structure was assessed by the results of ultrasonic tests through the pre-installed tubes, according to the test results, no defects were found.

It is known from the experience of using polymer solutions that long polymer chains are destroyed at high speeds, for example, when pumping with a centrifugal pump. To confirm this fact, an experimental pumping of solutions with a viscosity of 80 and 250 s by centrifugal and worm pumps was performed. According to the results of the experiment, it was found that regardless of the initial viscosity of the solution after pumping with a centrifugal pump, the conditional viscosity decreases to 30 s (value for water), which indicates the destruction of the structure of the solution; in the case of using a worm pump, this process does not manifest itself [10].

6. Full-scale tests of piles made under the protection of a polymer solution

To assess the bearing capacity of drill piles, made under the protection of polymer drilling mud, pilot piles were made at the test site (figure 4), which were then tested with a static pulling load following GOST 5686-2012 (figure 5).

The experimental site was located on the territory of JSC ‘Research Center Construction’ in Moscow. Based on the results of engineering and geological surveys, it was determined that from the surface to a depth of 2.2 m, there are bulk man-made soils, represented by sandy loam and loam with construction waste, below which, to a depth of 3.2 m, there is a layer of stiff loam, and below, to a depth of 4.7 m, alluvial sands of medium size, medium density, the base of which is plastic sandy loam (figure 6).
Since the interaction of polymer solutions with sandy soils was investigated within the framework of this work, the design of the experimental piles was adopted in such a way as to estimate the friction along the lateral surface in sandy soils.

To achieve this goal, the piles were made in the following sequence:
- drilling a boreholes with a diameter of 300 mm to a depth of 3 m and installation a casing pipe with a diameter of 273 mm;
- drilling a borehole to a depth of 4.7 m using a hollow (through) auger with a diameter of 250 mm and filling the borehole when lifting the tool with drilling mud;
- exposure of the well with drilling mud for at least 12 hours;
- concreting the pile through the concrete pipe from bottom to top;
- immersion of a spatial reinforcement cage in a filled well.

**Figure 4.** The layout of test piles (a) and the general view of the test site (b).

**Figure 5.** Test of the pilot pile.
As part of the experimental fieldwork, 8 piles were carried out, two piles for each mortar used, the parameters of which are given in table 1. A month after production, each pile was dug up to the level of the bottom of the casing and to eliminate friction in the level of the fill soil around the siege pipe installed picking up from wooden boards and backfilling (figure 7). After the completion of the preparatory work, each pile was tested with a static pull-out load according to GOST 5686-2012, the results are shown in figure 8. As can be seen from the graphs, the pull-out resistance of piles made under the protection of a bentonite solution is, on average, 30% lower than at piles with polymer mortar. At the same time, the lowest bearing capacity was recorded for piles made under the protection of Polyflok 1520 polymer solution, which has the highest viscosity. The bearing capacity of BAUER mortars (703 and 709) is approximately the same (figure 8).

Table 1. Main indicators of drilling muds used in field research.

| Core indicators | Dry matter consumption (kg/m³) | Marsh funnel viscosity (c) |
|-----------------|--------------------------------|---------------------------|
| Bentonite solution, ρ=1.03 kg/m³ | 30 | 35 |
| Bauer SLURRY LTP 709 | 1.6 | 100 |
| Bauer SLURRY LTP 703 | 5.25 | 80 |
| Polyflok 1520 | 1.8 | 120 |
7. Conclusion

The article presents the main results of work on the analysis of the possibility of using polyacrylamide drilling muds in the installation of drill piles, barrettes and slurry walls in sandy soils.

In the course of trough tests, it was noted that the main indicative characteristic of a polymer solution is viscosity, and not density, as in bentonite solution. According to the results of trough tests, the stability of the trench wall made of coarse sand is ensured at a conditional viscosity of at least 80 s
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(according to the Marsh funnel), for coarse sand this value increases to 120 s. At lower values of viscosity, the walls collapse.

The studies carried out have shown that when a soil excavation is arranged under the protection of a polymer drilling mud, it soaks the surrounding soil massif, changing its properties.

As a result of comparing the shear tests of soil samples impregnated with a polymer solution and distilled water, it was concluded that the difference in the obtained values as a whole does not exceed the statistical spread, that is, the presence of a polyacrylamide solution does not significantly affect the strength properties of sands of various sizes and densities.

To assess the effect of the polyacrylamide solution on the strength of the concrete-soil contact, a series of shear tests were performed, in which the samples were moved along the concrete surface. As a result of comparing the results of the tests carried out on soil samples impregnated with a polymer solution and distilled water, it was concluded that, as in the case of shear tests described above, the difference in the obtained values does not exceed the statistical spread of values. The presence of a polyacrylamide solution does not significantly affect the strength properties of the concrete-sandy soil contact.

Based on the results of a comparison of a full-scale test of piles with a pulling load, it was found that the resistance of a pile along the lateral surface of sandy soil in the case of using polyacrylamide drilling mud is on average 30% higher than in the case of using bentonite mud.

As a direction for further research, it is planned to study the interaction of polyacrylamide drilling muds with clay soils and to study the effect of the properties of polyacrylamide fluids on the stability of the walls of trenches.

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