The acceleration of the peat secondary consolidation due to the sorption of bound water with disperse clay

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Abstract. According to observations at the experimental site, the primary consolidation of the 6-6.5 m peat layer completed in 3-5 years after the sandy embankment was filled on. Secondary consolidation of peat caused by the removal of bound water from micropores and channels within vegetation remains is the cause of settlement that has not stabilized for decades. The aim of laboratory research was to evaluate the effects of two methods for peat settlement stabilization at the stage of secondary consolidation – vacuuming and sorption of bound water of disperse clay. Tests were carried out with peat, which has a degree of decomposition of 40-45 %, a density of 0.98–1.12 g/cm³, a void ratio of 11.8–13.8. Samples with a diameter of 87 mm and a height of 30, 50 and 70 mm were set into odometers and maintained under a load of 25, 50 and 100 kPa for 5-6 months, after that experiments to stabilize secondary consolidation were started. In contrast to vacuuming, the use of pre-dried clay with the following properties turned out to be very effective: maximum hygroscopic water content 43%, liquid limit 198%, plastic limit 58%, specific surface area 411 m²/g. The volume of clay was about 20% of the volume of peat samples. Deformations of samples due to water sorption by clay increased within 2-4 days and reached 0.09-0.11 of their initial height. The penetration of clay into the peat can be performed by drilling of boreholes, vibration stamping and other methods.

1. Introduction

During the warm interglacial period that began 10-12 thousand years ago, the vast plains of North-West Russia and Western Siberia became swampy. The presence of few meters of peat deposits significantly complicates construction. If during the construction of buildings and laying of communication peat is pierced with pile foundations, and at arranging the transport routes it is replaced by mineral soil, then at the rest territory of the cities and enterprises carrying out continuous excavation of this organic soil is not possible. Here they use the method of peat loading, dumping a layer of sand several meters thick on the surface of the swamp. The example is Arkhangelsk, that was built on swampy peatland shows that the peat settlement under a sand embankment does not stabilized for several decades. In areas of the city where construction was carried out in the 70s of the last century, it is currently developing at a rate of 5-15 mm/year, which causes damage to roads, sidewalks etc. (Fig.1). Over the past two decades, the problem of stabilizing peat settlement has become even more urgent, as the city is undergoing intensive compaction of existing districts, where it is very difficult to complete the excavation of peat and replace it with mineral soil.
A peat has specific two-level structure - closed micropores and channels are contained inside large plant residues. Primary consolidation is caused by the removal of free water from macropores between large particles, and secondary - bound moisture from micropores and channels [1;2;3;4;5]. Our observations at the experimental site showed that the change in the slope of the graphs shown in Fig. 2, indicating the transition from primary to secondary consolidation, takes place 3...5 years after the filling of the embankment [6]. Therefore, long-term settlement of the city territory is caused by secondary consolidation of peat.

Figure 2. Surface setting at the test site with the initial thickness of the peat layer of 6-6.5 m at the thickness of the sand embankment: 1 – 0.9 m; 2 – 1.7 m; 3 – 2.2 m; 4 – 2.4 m; 5 – 3.7 m [6].

A very common way to accelerate the consolidation of peat is to create an additional load on it by dumping an additional temporary embankment. But for secondary consolidation, its effectiveness is low. As it can be seen from Fig. 2, the coefficient of secondary consolidation, which is equal to the tangent of the angle to the x-axis of the graphs plots for the stages of secondary consolidation, is increased only by 2 times from 0.025 to 0.050 - in the height of the embankment by four times, from 0.9 to 3.7 m. In addition, a temporary embankment delays the introduction of new objects into operation. The next way to stabilize the settlement is the usage of vertical drains, which have been supplemented by vacuuming. Vacuuming can be combined not only with vertical drains, but also with a temporary additional load [7;8]. It is clear that vertical drains that shorten the path of pore water filtration affect the course of primary consolidation, but vacuuming, apparently, can also contribute to the removal of bound moisture from micropores and channels.

Numerous studies on a peat stabilization with binders – cement, lime, gypsum – have shown that the required application of binder is very significant - from 100 to 400 kg per 1 m$^3$ of peat [1;9].

Figure 1. Manifestations of long-term peat settlement at the base of structures: a) destruction of the blind area of the building, b) setting of the sidewalk around the well manhole.
Solutions of binders penetrate the macropores, pushing the particles apart and compacting the peat, and create a spatial structure. On the contrary, the introduction of dry mixtures can contribute to the consolidation of peat due to the sorption of pore moisture. However, the same result at the stage of secondary consolidation is likely to be achieved when using inert highly dispersed materials, such as clay powders.

The aim of this research was to evaluate the effects of two methods for stabilization peat settlement at the secondary consolidation stage. Peat samples that had been exposed to constant compressive stresses in compression devices for a long time were vacuumed and treated with montmorillonite clay powder.

2. Materials and methods
We tested undisturbed samples taken at the neighborhood of Arkhangelsk on an undeveloped, undrained swamp from pits from a depth of 0.5-0.8 m. Initial properties of peat: decomposition degree 40-45 %, density 0.98-1.12 g/cm³, water content 7.70–10.60, void ratio 11.8–13.8. Here and further, water content is given as the ratio of the mass of water to the mass of the solid phase. The structure of the peat is shown in a photo taken with a scanning electron microscope Vegan Tescan 3 (Fig. 3).

![Figure 3. Structure of the studied peat.](image)

The experiments were carried out in oedometers with a diameter of samples 87 mm, a height of 30, 50 and 70 mm. The load on the samples $p$ was 25, 50 and 100 kPa and applied at once in one-step, as required by standards for determining consolidation coefficients. The devices were placed in a room with a temperature of 5-12°C, which slowed down the decomposition of organic matter of peat. The load was maintained for 156-195 days until the rate of deformation development decreased to 0.005 mm/day. After that, they started experiments to stabilization.

3. Research results
A characteristic graph of the dependence of deformations $\varepsilon$ of the peat sample on time $t$ is presented in Fig. 4a. As we can see, the primary consolidation of peat was completed 8 hours after the start of the experiment. When testing other samples, the duration of this stage varied from 8 to 22 hours.
Figure 4. The results of peat compression testing: a) development of deformations of one of the samples in time; b) the dependence of deformations of the load: 1 – at the end of primary consolidation, 2 – at the end of the test.

Figure 4b shows the compression dependencies \( \varepsilon = f(p) \) for the stage of completion of primary consolidation and at the time of completion of compression tests, where a logarithmic scale is traditionally used on the abscissas axis. As we can see, the deformations of peat vary from 0.1 to 0.5 depending on the load.

Six samples were subjected to vacuum after standard compression tests were completed. To do this, the lower chambers of the devices were connected to the receiver of the vacuum pump (Fig. 5a). The pressure below atmospheric pressure by 45-50 kPa was maintained for 4 days. As it can be seen from the dependency shown in Fig. 5b with solid line, the effect of the vacuum, especially at a load of 50 and 100 kPa, was very small. The deformations of peat samples have not changed much either.

Figure 5. Vacuuming of peat samples: a) scheme of the experiment; 1- odometer, 2 – receiver, 3 – pressure gauge, 4 – vacuum pump; b) the dependence of deformations of the load (1). The dotted line shows deformations during primary consolidation (2) and the completion of the compression test (3).

The other six samples were brought into contact with a powder of montmorillonite clay. Properties of clay: hygroscopic water content 6%, maximum hygroscopic water content 43%, liquid limit 198%, plastic limit 58%, specific surface area 411 m\(^2\)/g. Pre-dried clay was poured on top of the samples - into specially opened holes with a diameter of 14 mm in the pistons of oedometers. The volume of clay was about 20% of the volume of samples. Deformations of a peat due to water sorption by clay increased within 2-4 days and reached 0.09-0.11 from the initial height of the samples or 0.12-0.16 from the height of the samples after completion of compression (Fig. 6). The clay water content at the
end of the experiments reached 0.58-0.60, the peat water content decreased on average from 5.81 to 4.80.

4. Discussion
The reason for the small effect when vacuuming samples is, apparently, the almost complete absence of macropores in the peat at the stage of secondary consolidation (especially at loads of 50 and 100 kPa). Bound moisture prevails in micropores, and to remove it, it is necessary to create a significantly greater underpressure than was the case in our experiments. We note that the execution of such works in production conditions is quite complex and expensive procedure.

On the contrary, the rapid increase in deformations was the case when exposed to disperse clay. When the thickness of the peat layer is 2-3 m under the sand embankment, the penetration of clay, for example, into the boreholes will provide additional peat draft by 20-30 cm, thereby eliminating the long-term development of deformations and damage to structures shown in Fig. 1.

The proposed method of a peat stabilization is very prospective, especially taking into account the presence in Arkhangelsk of large volumes of highly dispersed waste from one of the enterprises of the diamond industry – saponite clays.

Figure 6. Deformation of peat samples due to water sorption by clay: a) scheme of the experiment: 1-odometer, 2 – piston, 3 - holes filled with clay powder; b) the dependence of deformations of the load (1). The dotted line shows deformations during primary consolidation (2) and completion of compression tests (3).

5. Summary
1. Deformations of peat caused by its secondary consolidation have been developing for decades, and specific methods are required to settlement stabilizing, which differ from the methods of acceleration at the stage of primary consolidation.

2. Treatment of peat with clay powder contributes to its stabilization at the stage of secondary consolidation due to sorption of water contained in micropores.

6. References
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