IOP Conf. Series: Materials Science and Engineering **365** (2018) 042069 doi:10.1088/1757-899X/365/4/042069

Numerical simulation for regular drainage in peat soil

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Abstract. The development of wetlands requires lowering considerably the water table. This objective used to be achieved by arranging regular drainage. As practice shows, the preset depression of the water table has not been achieved in many cases. It is caused by decrease of the peat water permeability due to its compression under the removal of water hydrostatic uplift and by clogging processes in the peat. The analytical methods used to ignore the above factors for drainage design. This article suggests an algorithm of numerical simulation for regular drainage using PLAXIS 2D software. Its verification has been made in accordance with the field observation data, which had being collected for 1.5 years in Arkhangelsk within 500×600 m site built up with low-rise flat blocks.

The thickness of the least decomposed peat layer is from 3.0 to 4.2 m within the site. The peat from the top is loaded by the construction and household debris layer with up to 0.6 m thickness mixed with decomposed organic matter. The peat is under laid by impermeable stiff clay. The stratification and properties of the soils are taken in accordance with the survey results. The regular drainage was constructed in the seventies of the last century out of 300 mm diameter asbestos-cement perforated pipes placed with 140 m spacing with the drain filter made of crushed stone. The pipes were buried with its bottom at the depth from 3.3 to 3.4 m from the daylight surface. The drainage trenches were backfilled with sandy soil.

The position of the depression curve was being monitored within the studied site. With this aim, we drove piezometers into the soil at the distance of 6, 18, 30 and 45 m from the drainage pipes. The water level in the piezometers was measured with periodicity of 30-60 days. The results of monitoring showed that the difference of ground water depth values in the piezometers reach 2.3 m with the distance increase from the drain. The variation of the water table within an annual cycle as per an individual piezometer is from 0.21 to 0.37 m.

It is shown that the results of drainage design by way of analytical methods give considerable deviations from the actual ground water levels.

The numerical simulation for water level depression with the PLAXIS software is performed by step-by-step approximation. The first step considered the decrease of the peat permeability factor due to removal of the water hydrostatic uplift and the second step considered the change of the permeability with time due to clogging.

Considering the peat permeability with time allows to get ground water depression curve closer to the data obtained by site monitoring.

1. Introduction

Preparation of wetlands for construction requires costly measures of water depression and filling the surface with a sand layer up to several meters high. The results of long-term operation of regular pipe drainage systems show that they cease to provide the required water table position after a few years. This is associated with a considerable change in peat permeability due to its consolidation under the sand fill load, clogging processes in the peat, and reduction of drain filter permeability by small organic and mineral particles carried over by water flow [1-3, 12, 13]. Peat water permeability reduction with time established in the course of laboratory testing is due to pore clogging with fine particles [8, 10, 11]. The content of fine particles in peat depends on its decomposition degree (the quantity of humus). The reduction of drain filter water permeability is determined by the presence of fine particles in soil, which can be washed away by the water flow. Drainage system survey results prove that soil suffosion may cause the permeability factor of stone covers to decrease tenfold [1].

Numerous studies demonstrate that peat of natural structure is a water permeable soil, and peat at 100 kPa is water impermeable [2]. Water table depression in drainage-affected areas leads to additional peat compaction and, therefore, permeability reduction [3, 14].

Drainage structures may contribute to the accumulation of small mineral and organic particles in the stone cover [1]. A considerable disadvantage of many drainage systems is the absence of return filters between the stone cover and the backfilling material. According to drainage survey results, up to 40% of drain pipe cross section may become blocked with fine soil particles and organic matter unless the pipes are cleaned regularly [1]. Besides, the water table may also be influenced by alteration of groundwater runoff conditions through pile foundation construction, sand filling, etc. [7].

The article provides the results of monitoring the regular drainage system constructed in the 1970s in the city of Arkhangelsk, as well as the results of its analytical calculation and numerical simulation.

2. Laboratory experiments

A built-up area of 500×600 m was studied. The peat layer of 3.0 to 4.2 m thick is covered with a sand fill of 0.6 to 0.8 m thick. The peat is underlain by impermeable stiff glacial loam. The drainage is made of 300 mm diameter pipes with a 150 mm drain fill of crushed stone. The pipes are spaced 140 m at the depth of 3.2 to 3.5 m. After drain pipe installation, the trenches were backfilled with sand. Pipe inspection and cleaning wells are provided with the maximum spacing of 50 m.

Undisturbed peat samples for laboratory testing were taken from pits at the depth of 0.9 to 1.2 m. Peat physical properties are as follows: density 1.02 to 1.04 g/cm^3, moisture content 9.5 to 10, porosity coefficient 14.5 to 15, degree of decomposition 8 to 10%.

Permeability was studied in compression and filtration instruments on samples 5 cm high and 8.7 cm in diameter. According to the test results, the initial peat permeability factor k_0 was 0.6 m/day. The permeability factor in the result of compression can be found using the formula [9]:

$$\log\left(\frac{k}{k_0}\right) = \frac{\Delta e}{c_k},$$

Where Δe is the porosity coefficient change,
c_k is the coefficient of 3.8.

The loam underlying the peat is a permeable soil type, $k = 3\cdot 10^{-7}$ m/day.

Water table position was monitored within two profiles, each having 4 piezometers installed at the distance of 5, 18, 30 and 45 m from drain pipes. The piezometers were made of plastic pipes 50 mm in diameter and 3.3 m long, perforated at the bottom. Geotextile was used as filter. Water level in piezometers was measured with an interval of approx. 60 days within one year and a half. Monitoring results are given in Table 1. Due to variable soil surface elevations, the water table given in the table is from the soil surface elevation directly above the drain pipe.

The analytical calculation of depression curve for regular drainage was performed in accordance with the well-known formula [5, 6]:

$$y = \sqrt{h_{\max}^2 - \frac{W}{k}\left(\frac{L}{2} - x\right)^2},$$

Where x, y are the respective coordinates of the depression curve (with the drain pipe axis assumed as the origin),

h_{max} is the water table in the middle between the drains,
W is the infiltration (permeation of atmospheric precipitation into the soil),
k is the peat permeability factor (ground water velocity with a unity head gradient),
L is the drain spacing.

The value of h_{max} can be calculated using the formula

$$h_{\max} = \sqrt{\frac{WL^2}{4k} + h^2},$$

where h is the water height in drain pipe.

Table 1. Water table monitoring results

Date of measurement	Water table depth, m, at the distance from drain pipes, m			
	5	18	30	45
01.16	2.18 / 2.37	1.20 / 1.21	0.68 / 0.76	0.34 / 0.36
03.16	2.30 / 2.43	1.31 / 1.28	0.84 / 0.87	0.49 / 0.57
05.16	2.06 / 2.28	1.21 / 0.97	0.57 / 0.62	0.37 / 0.43
07.16	2.35 / 2.35	1.36 / 1.06	0.76 / 0.72	0.45 / 0.47
09.16	2.17 / 2.36	1.21 / 1.03	0.80 / 0.88	0.48 / 0.49
11.16	2.08 / 2.32	1.19 / 0.97	0.66 / 0.74	0.37 / 0.38
01.17	2.20 / 2.40	1.25 / 1.14	0.75 / 0.84	0.45 / 0.50
03.17	2.28 / 2.45	1.37 / 1.31	0.82 / 0.86	0.54 / 0.59
05.17	2.11 / 2.33	1.18 / 0.94	0.61 / 0.69	0.41 / 0.44

Note: The numerator is the water table for profile № 1, and the denominator is the same for profile № 2.

It must be noted that the inspection of wells identified that 25 to 30% of the drain pipe cross section was silted by accumulated mineral and organic particles. Due to low permeability of peat, clogging of drain filters and reduction of drain pipe water-carrying capacity were not considered.

Infiltration W was determined as the difference of precipitation amount and surface evaporation. The first variable was assumed as 550 mm per year according to meteorological observation data. The second variable was assumed as 190 mm per year based on the experimental Mayer's curves depending on the air temperature [4]. Considering the low permeability factor, the precipitation inflow was assumed as uniformly distributed over the one-year cycle for numerical simulation purposes.

The results of water table calculation at various distances from the drain by the analytical method are given in Table 2. A significant deviation of the analytical calculation results from the actual water table position was discovered: the deviation reaches 0.20 to 0.48 m.

Table 2. Water table position according to calculation results and monitoring data relative to soil elevation above drainage

Water table position determination method	Water table depth from soil elevation above drainage, m, at the distance to drain pipes, m			
	5	18	30	45
Monitoring	2.19 / 2.35	1.26 / 1.10	0.72 / 0.78	0.43 / 0.47
Analytical	2.29	1.58	1.17	0.86
Numerical simulation	2.47 / 2.40	1.59 / 1.38	1.27 / 1.06	1.11 / 0.88

Note: The numerator is the water table depth for profile № 1, and the denominator is the same for profile № 2.

3. Numerical simulation

Unlike analytical calculation, numerical simulation allows taking into account the non-uniformity of geotechnical conditions, permeability anisotropy, variation of peat permeability at consolidation, and other factors. Simulation was performed using PLAXIS 2D software package. Considering that sphagnum peat does not show signs of permeability anisotropy, equal permeability factors in vertical and horizontal directions were adopted [8].

Numerical simulation of water level depression in PLAXIS software was performed using gradual approximation to the actual water table position:

- the first step considered the decrease of peat permeability factor due to peat compression when water hydrostatic uplift was removed. The calculation was carried out for the spring season with additional infiltration owing to snowmelt water inflow;
- the second step considered the change of permeability with time due to clogging processes in peat (the latter contains a lot of fine particles that cause permeability reduction in the presence of filtering flow).

Figure 2 shows depression curves for profile № 2 based on the actual water table position, the results of analytical calculation and numerical simulation. The deviation of the numerical simulation results from the actual water table position reaches 0.28 to 0.41 m.

At the second step, the maximum coincidence of the design depression curve with the actual water table position was ensured by adjusting the peat permeability factor. As it was mentioned above, the reduction of peat permeability with time is associated with pore clogging by fine particles contained in peat in large quantities. Table 3 gives the results of depression curve numerical simulation for profiles № 1 and № 2 with reduction factors 1.9 and 1.5 to peat permeability factor, respectively. The factors obtained ensure the most exact approximation of the design depression curve to the actual water table position (monitoring data). As an example, Figure 2 shows depression curves after gradual approximation of water table for profile № 2.

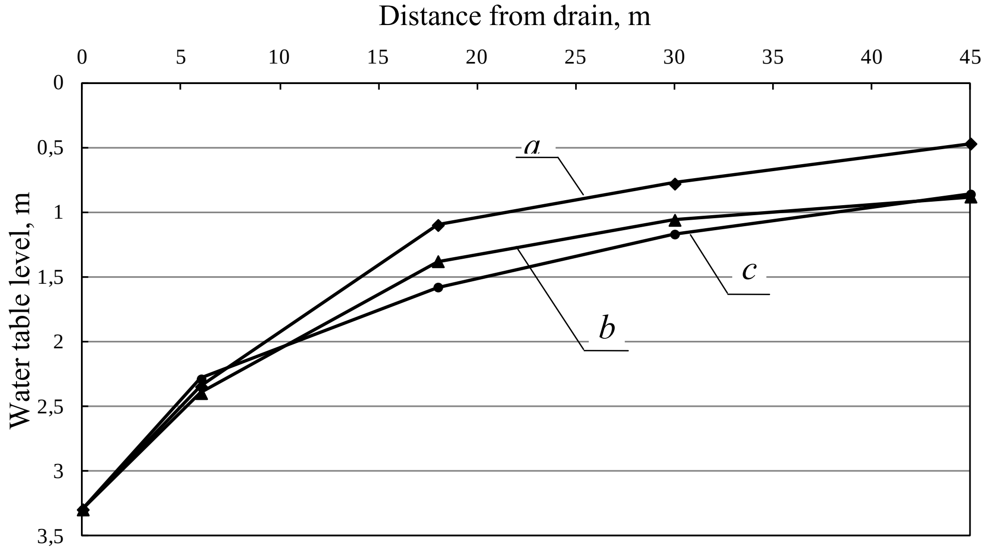

Figure 1. Depression curves for profile № 2: *a* – monitoring data, *b* – numerical simulation, *c* – analytical calculation

Table 3. Water table position according to calculation results and monitoring data relative to soil elevation above drainage

Water table position by numerical simulation data	Water table depth from soil elevation above drainage, m, at the distance to drain pipes, m			
	5	18	30	45
profile № 1 profile № 2	2.17 2.28	1.11 1.09	0.73 0.75	0.56 0.54
deviation from actual position, Δ, m	+0.02 +0.07	+0.15 +0.01	-0.01 -0.03	-0.13 -0.07

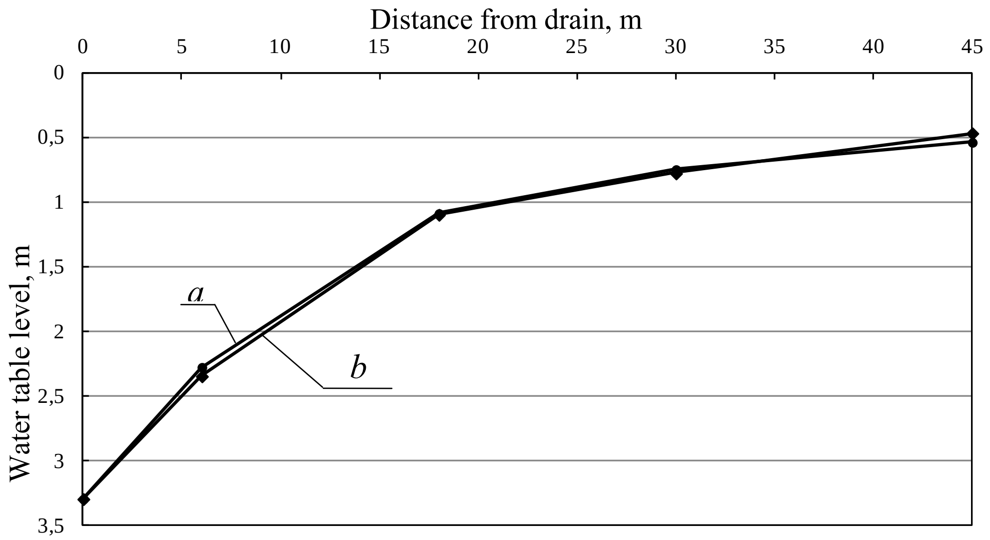

Figure 2. Depression curves for profile № 2:
a – monitoring data, *b* – numerical simulation results

Figure 2 shows that the deviation of the water table position by analytical method from the actual position by numerical simulation in PLAXIS software does not exceed 0.15 m. A slight calculation error might be due to peat permeability variation in plan and through the soil thickness. Therefore, to achieve a more accurate forecast for drainage design in peaty soils, reliable information on the water permeability of the base must be obtained in the course of geotechnical survey. In addition, the standard set of laboratory tests must be complemented with the assessment of peat water permeability change in the course of compaction with due consideration of clogging processes.

4. Conclusions

1. The results of water depression calculations in drainage-affected area by analytical methods in peat soils give considerable deviations from the actual ground water levels.
2. For a more reliable forecast of water level depression when designing drainage systems in peaty soils, specific peat properties need to be considered: permeability variation when removing water hydrostatic uplift, clogging processes and other factors. This can be done by adjusting the procedures implemented in software packages using the final element method.
3. Consideration of such factors as peat permeability variation under compression and peat clogging with time allows for better approximation of the depression curve obtained through numerical simulation to the actual water table position obtained by site monitoring.

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